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ESL-TR-91-44

A STUDY OF AIRBASE FACILITY/UTILITY ENERGY R&D REQUIREMENTS

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93-01572

APRIL 1992

FINAL REPORT

MARCH 1990 - JULY 1991

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1992	Final Report, March 1990 - July 1991

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
A STUDY OF AIRBASE FACILITY/UTILITY ENERGY R&D REQUIREMENTS	F29601-C-87-0001
6. AUTHOR(S) Gerald G. Leigh, Ph.D.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) New Mexico Engineering Research Institute University of New Mexico Albuquerque, New Mexico 87131-1376	8. PERFORMING ORGANIZATION REPORT NUMBER SS 2.16(4)
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Civil Engineering Laboratory Air Force Civil Engineering Support Agency Tyndall Air Force Base, Florida 32403-6001	10. SPONSORING/MONITORING AGENCY REPORT NUMBER ESL-TR-91-44 Vol. 1 of 3

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The objective of this project was to identify USAF airbase facility/utility energy needs over the next 30 years, to evaluate new energy technologies that might be used to help meet these needs, and to recommend R&D efforts that could assist in this process. The existing and projected world energy situation was reviewed, data on USAF airbase energy consumption and costs were analyzed, and new USAF systems and projected force structures were examined as to influences on airbase energy consumption. Baselines of current and projected energy consumption and associated costs were established. Twenty-three (23) new energy technologies were reviewed, and 15 were identified as having potential benefits for USAF airbases. Recommendations for R&D to assist this process are provided.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Airbase energy systems; USAF energy consumption; new energy systems; energy costs; energy R&D.	
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	Unclassified	Unclassified	Unclassified

NSN 7540-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18

EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this project was to identify United States Air Force (USAF) airbase facility/utility energy needs over the next 30 years, to evaluate new energy technologies that might be used to help meet these needs, and to recommend R&D efforts that could assist in this process.

B. BACKGROUND

The USAF operates more than 260 airbases, air stations, and other installations at numerous locations all over the world. The operation of these airbases, each similar to a small city, in a posture of readiness requires large amounts of energy for electric power, heating and cooling of buildings, and the operation of onbase systems. Increasing worldwide and national energy consumption and escalating energy costs over the past several years, along with forecasts of reduced defense budgets, are matters of serious concern and cause major difficulties for airbase operators and energy managers. The ever-increasing recognition of the many links between energy consumption and environmental problems worldwide further complicates the problems facing airbase energy managers. New policies and regulations, designed to help reduce environmental pollution, are forcing changes in energy-related operations and equipment. Airbase energy managers have, in recent years, faced increasing difficulties in supplying the energy, in its several forms, needed for airbase operations and in complying with the many mandated energy and associated environmental regulations and guidelines.

C. SCOPE

The existing and projected world energy situation was reviewed, data on Air Force (AF) airbase energy consumption and costs were analyzed, and new AF systems and projected force structures were examined as to influences on airbase energy consumption. Baselines of current and projected energy consumption and associated costs were established. New energy technologies were reviewed, and those having potential benefits for AF airbases were identified. Recommendations for R&D efforts to assist in the application of these new technologies are provided.

D. METHODOLOGY

New DOD energy policies and the recent Presidential Executive Order regarding facilities energy consumption were reviewed. An estimated baseline of current AF airbase facility/utility energy consumption was generated using data from the Defense Energy Information System (DEIS) database, questionnaires sent to all MAJCOMs and airbases, visits to all MAJCOMs and selected airbases, and a variety of previous reports. Analyses were accomplished to determine how these energy consumption rates and associated costs were distributed among MAJCOMs and individual airbases, how energy effective individual airbases and MAJCOMs were when compared on the basis of airbase size and local weather conditions, and how various AF operational systems influenced airbase energy effectiveness. An effort was then made to project this baseline 15 years into the future, assuming that no significant changes in USAF size and mode of operations were to occur.

There is little evidence to support the assumption of no significant change. To understand what changes in AF size and operations might occur over the next 30 years, AFSC Product Divisions were visited, data on projected force structure and airbase closures were obtained, and information was gathered on worldwide energy projections. A revised baseline of future energy consumption and costs was then developed.

Many energy-saving and cost-reducing energy technologies are now approaching maturity and others are under development. Some of these oncoming technologies could be employed to ease AF energy problems and reduce associated energy costs. An extensive literature search was done, and emerging technologies that could potentially benefit the Air Force in the near term, mid term, and far term were examined. A summary of how each works and its current state of development is provided.

E. RESULTS

This study revealed that, in 1989, AF facilities/utilities energy consumption was approximately 111 million MBtus and cost slightly over $850 million. Based on the above assumption of "no change," it has been projected that, by the year 2005, total USAF facilities/utilities energy consumption will have declined to approximately 110 million MBtus but will cost between $1.24 and $1.62 billion, depending on future cost escalation. Using the above information on projected changes, a revised baseline of AF energy consumption and associated costs was constructed. By 2005, AF total facilities/utilities energy consumption should decline to approximately 93.5 million MBtus and cost between $1.07 and $1.37 billion.

Twenty-three (23) new energy technologies were reviewed and fifteen (15) were considered to have direct applications to AF airbases. How they would be used and what benefits they might bring to the Air Force are then discussed in some detail.

F. CONCLUSIONS

With the projected changes in force structure and basing, the Air Force will likely meet the newly mandated DOD energy goals through the year 2000. Any further reductions beyond that time are unlikely without the substantial use of new technologies. However, AF costs for this energy will likely increase sharply, perhaps as much as 50 percent over 1989 costs by the year 2000.

G. RECOMMENDATIONS

Several of the emerging technologies need further research and development to adapt them to unique military needs. Ongoing Air Force R&D programs can be focused to help accelerate the development and application of these new energy technologies to meet AF energy requirements. Recommendations have been made as to which of these facility/utility energy technologies should be considered for Air Force-supported R&D. Among those recommended are the following: (a) near term--energy-effective lighting systems, cogeneration, solar thermal systems, wind energy systems, etc.; (b) mid term--mobile solar photovoltaic systems and hybrid solar/thermal photovoltaic systems; and (c) far term--hydrogen fuel systems and high-temperature superconducting electrical systems.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, Albuquerque NM 87131-1376, under Contract F29601-87-C-0001 for Headquarters Air Force Civil Engineering and Support Agency/Air Base Operability and Repair Branch (HQ AFCESA/RACO), Tyndall AFB FL 32403-6001.

This report summarizes work done between March 1990 and July 1991. HQ AFCESA/RACO Project Officers were Ms LeAnn Tichenor and Mr Reza Salavani.

This is Volume I of a three-volume report. Volume II is entitled Energy Consumption on USAF Bases (DEIS Data). Volume III contains annotated bibliographies. Volumes II and III are available from HQ AFCESA/RACO.

This report has been reviewed and is approved for publication.

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LIST OF ABBREVIATIONS

AF	Air Force (of the United States)
ATC	Air Training Command
EBF	Energy Budget Figure ($MBtu/ft^2$)
CSR	Central Solar Receiver
MAC	Military Airlift Command
MAJCOM	Major Air Command
MBtu	Million British thermal units
PACAF	Pacific Air Forces
SAC	Strategic Air Command
USAF	United States Air Force
USAFE	United States Air Forces Europe

CONVERSION OF ENERGY UNITS TO MILLION BRITISH THERMAL UNITS (MBtu)

Electricity	3.413 MBtu/MW-hr	Photovoltaic	3.413 MBtu/MW-hr
Coal (Anthracite)	25.4 MBtu/ton	Saturated Steam	1.34×10^{-3} MBtu/lb
Coal (Standard)	25.58 MBtu/ton	Propane	95.5×10^{-3} MBtu/lb
Geothermal Steam	1.34×10^{-3} MBtu/lb	Wind	3.413 MBtu/MW-hr
Geothermal Electricity	3.413 MBtu/MW-hr	Hydroelectric	3.413 MBtu/MW-hr
Solar Thermal	1×10^{-6} Btu/Btu	Fuel Oil Distillate (FSD)	5.825 MBtu/bbl
Coke	25.38 MBtu/ton	Fuel Oil Residual (FSR)	6.287 MBtu/bbl
Refuse Derived Fuel	6.09 MBtu/ton	Fuel Oil Reclaimed (FOR)	5.0 MBtu/bbl
Natural Gas	1.03 MBtu/(1000CF)	Wood	17.0 MBtu/cord

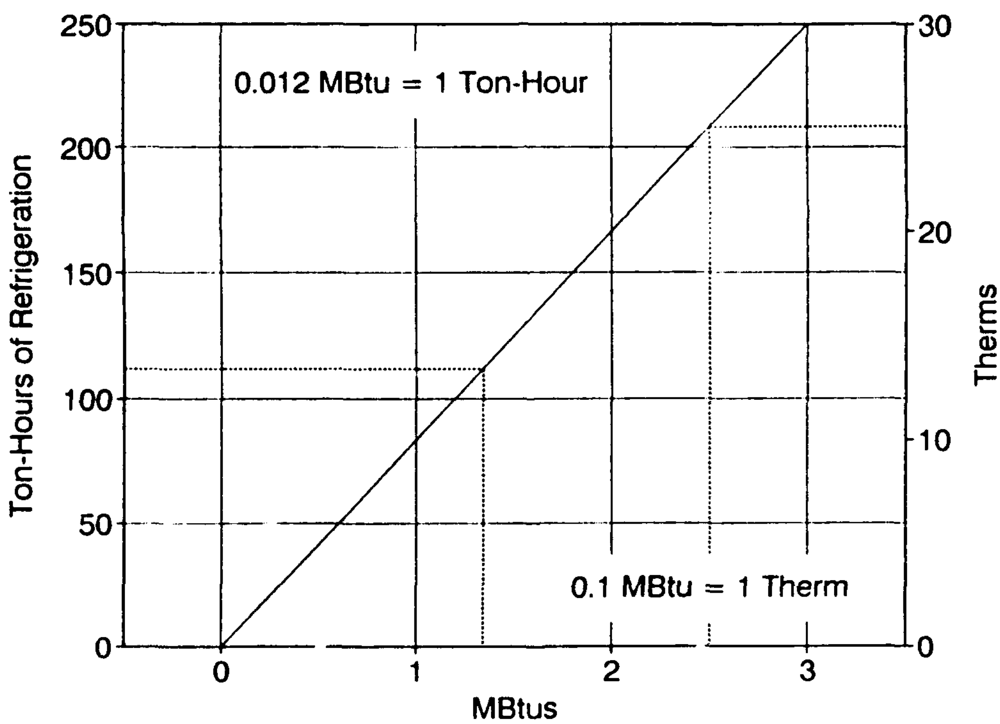

Figure A. Conversion from Ton-Hours of Refrigeration and Therms to Millions of British Thermal Units (MBtus).

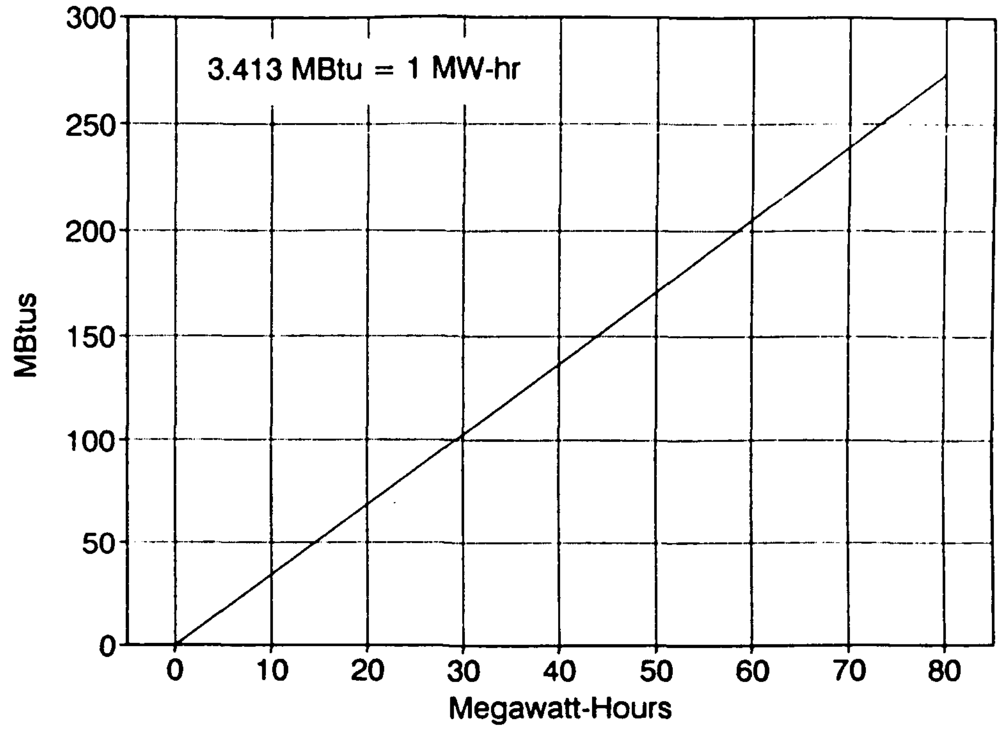

Figure B. Conversion from Millions of British Thermal Units (MBtus) to Megawatt-Hours.

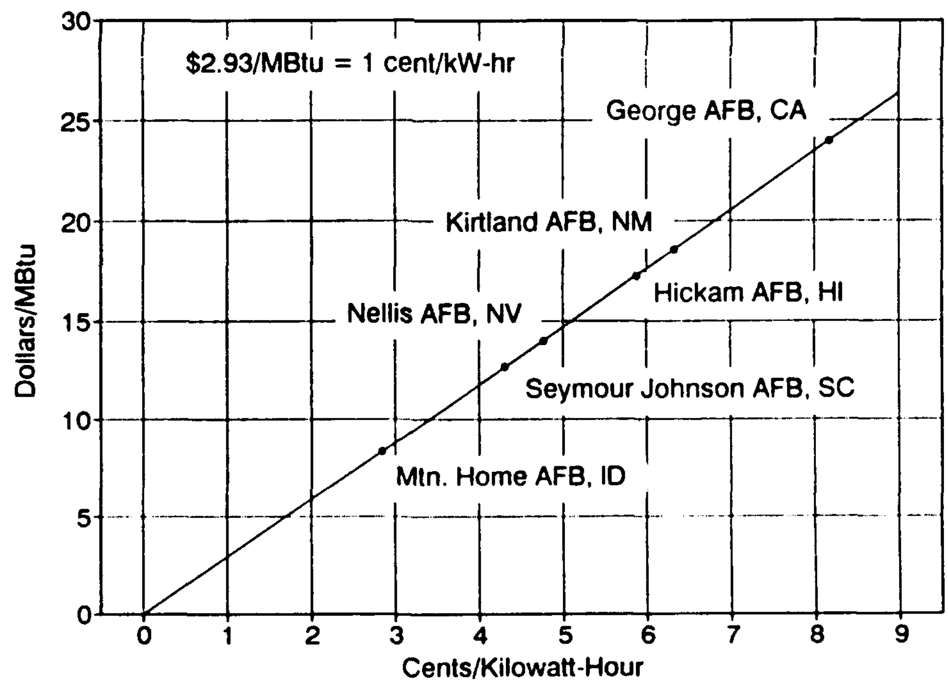

Figure C. Cost Conversion from Cents/Kilowatt-Hour to Dollars/Million British Thermal Unit ($/MBtu). Includes 1989 electricity costs for selected airbases.

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SECTION I
INTRODUCTION

A. OBJECTIVE

The objective of this project was to identify United States Air Force (USAF) airbase facility/utility energy needs over the next 30 years, to evaluate new energy technologies that might be used to help meet these needs, and to recommend R&D efforts that could assist in this process.

B. BACKGROUND

The United States Air Force (USAF) operates more than 260 airbases, air stations, and other installations at numerous locations all over the world (Reference 1). The operation of these airbases, each similar to a small city, in a posture of readiness requires large amounts of energy for electric power, heating and cooling of buildings, and the operation of onbase systems. More than 110 trillion British thermal units (Btus) of energy (equivalent to 18 million barrels of oil) are consumed by the Air Force (AF) annually for these facility/utility energy requirements. Energy costs of nearly a billion dollars each year constitute a large portion of the cost of operating these installations.

Increasing worldwide and national energy consumption and escalating energy costs over the past several years, along with forecasts of reduced defense budgets, are matters of serious concern and cause major difficulties for airbase operators and energy managers. Funds required for increased energy costs are not available for necessary military operations or the maintenance and repair of airbase facilities and systems.

The ever-increasing recognition of the many links between energy consumption and environmental problems worldwide further complicates the problems facing airbase energy managers. New policies and regulations, designed to help reduce environmental pollution, are forcing changes in energy-related operations and equipment.

Many energy-saving and cost-reducing technologies are now approaching maturity and others are under development. There is good reason to believe that some of these oncoming energy and cost-saving technologies can be employed to ease AF energy problems. Ongoing Air Force research and development (R&D) programs can be focused to accelerate the development and application of new energy technologies to meet unique AF needs.

To continue an effective energy-related R&D program, definition of the current AF energy/utility status is needed along with projections of energy requirements and technology possibilities for the future. New energy systems must be developed with a full understanding of the many issues and operational considerations influencing airbase energy consumption and costs, both now and in the future. The goal of this airbase energy/utility assessment project has been to define areas requiring research and development effort in the near term (1991-1996), mid term (1997-2005), and far term (2006-2020). The AF can then focus its energy R&D programs to help develop technologies to meet energy requirements in the most effective and affordable manner applicable to its mission.

R&D resources must be focused to ensure the development of reliable and cost-effective energy systems that will, in the near term, be of immediate assistance to airbase energy managers and ensure affordable energy security and capabilities in the future.

1. Energy Difficulties at Military Bases

The late 1980s and early 1990s have been times of great change throughout the world. Events in the Soviet Union and Eastern Europe are having monumental effects on our military organizations. The Gulf War in the Middle East has again revealed the instability in the world's energy supply.

Airbase energy managers have faced increasing difficulties in supplying the several forms of energy needed for operation of the base and in complying with the many energy mandates and associated environmental regulations and guidelines. Many events are happening outside of their area of control that adversely affect the stability and cost of the airbase energy supply.

In response to Defense Energy Program Policy Memorandum 86-6, which, beginning in 1985, required a 1 percent reduction in facility/utility energy consumption per year for 10 years, base energy managers have retrofitted and upgraded the energy performance of many buildings and energy systems, implemented numerous energy awareness and conservation programs, and begun to monitor more diligently the energy performance of all aspects of their bases with very beneficial results. However, many of the easy steps have already been accomplished. In the future it will become increasingly difficult to further trim base energy budgets without risk to mission performance.

As one would expect, airbase energy problems vary from region to region. For example, a drought in the western part of the United States during the past 4 years has left the major water reservoirs throughout the West very low and unable to provide hydroelectric power in the quantities available in previous years. The Western Area Power Administration (WAPA) has notified its customers, many of which are military bases, of substantially reduced allocations of WAPA supplied power (Reference 2). These military bases now must face increased purchases of commercially supplied power or find alternative means to compensate for this shortfall in electrical power. The situation may be further complicated by a recent congressional proposal regarding the release of water from the Glen Canyon Dam (Page, AZ) on the Colorado River. The current diurnal variations of water release to meet peak power demands has caused wide fluctuations in water level, resulting in erosion damage to the canyon, increased silt deposits, and damage to vegetation and wildlife. The congressional proposal mandates that water not be released to meet peak power demands but instead be released in a manner less environmentally damaging to the Grand Canyon (Reference 3).

In some locations, fuel supplies are limited by regional distribution systems. For example, the natural gas pipelines in Minnesota do not adequately meet the needs of all users during periods of peak consumption. To overcome this difficulty, the gas company has established a program of interruptible supply. Those who sign up for this program receive special beneficial rates, but must be prepared to shift promptly to an alternative fuel following notification. Grand Forks AFB (ND) has an interruptible fuel contract that saves them money overall, although it requires that the base maintain an alternative fuel system and associated equipment in a ready-to-operate status.[1]

The quality and reliability of electric power service provided to many military bases are becoming matters of concern. The increasing number of offbase customers and the greater loads on utility power lines are causing frequent interruptions in service and large variations in power quality. The ever-increasing reliance of military operations on electronic systems, computerized data banks, and computer-aided management analyses, all of which depend heavily on reliable, high-quality power, makes power disruptions a very serious matter.[2]

At Fort Irwin AFB (CA), summer peak power demand charges have escalated electric power costs beyond acceptable limits. To help reduce these costs, summer working hours

[1]Personal communication, Mr. John Ness, Northern States Power Co., St. Paul, MN, July 1990.
[2]Personal communication, utility system managers at USAF Major Air Commands, Summer 1990.

at the base have been moved up to 6:00 am. Refrigeration cooling systems are turned off shortly after midday, and workers are encouraged to leave work as the buildings become too hot for productive operations.[1]

A difficult situation has existed at US military installations in the Philippines over the past several years, as the Republic has struggled to meet an ever-increasing demand for electric power from an undersized, aging power system. Clark AFB and Subic Bay, two of the largest electrical customers for the Republic, have both been caught in this situation and have experienced serious brownouts. To solve the problem, Clark has been forced to utilize portable diesel generators as a temporary measure and to install 48 MW of semipermanent diesel-generating capacity to ensure adequate power for the base (Reference 4). These steps will undoubtedly increase the cost and complexity of operating Clark AFB.

The petroleum fuel situation in the US continues to worsen as national consumption increases and as domestic production declines. Dependence on foreign sources of crude oil is again at 50 percent (Reference 5). Exploration for new domestic sources continues to decline with fewer drill rigs in operation and fewer discoveries occurring. The Gulf War and the tension all over the world brought on by this crisis serve to emphasize our vulnerability to interruptions from foreign sources. The situation is further exacerbated by the many problems plaguing the transport of petroleum products. The 1989 Valdez oil spill, the large discharge into Galveston Bay, and the recent oil spill off the coast of California, have resulted in a massive public outcry against the continuation of current transport practices. The purchase of new double-hulled oil tankers, the imposition of tighter controls over shipping lanes and practices, and the restriction of shipping near certain pristine wetlands will increase the costs and difficulties associated with our continued heavy dependence on foreign sources of petroleum fuels. The bottom line is that airbases largely dependent on petroleum fuels are at risk, first from the potential lack of available fuel but more strongly from rising costs.

Electrical power supplies in the eastern half of the United States and in California are not promising. Demands for power are steadily increasing, while the number and capacity of generating plants attempting to meet the need are decreasing due to the age of the plants, increased operating costs, and environmental pressures. The projected crossover point where brownouts and possibly major blackouts could begin is 1995 (Reference 6).

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[1]Personal communication, Captain Kenneth A. Harshbarger, U.S. Army, Liaison Officer, Naval Civil Engineering Laboratory, Port Hueneme, CA, 19 September 1990.

This situation could have two possible implications for airbases. First, bases may not be able to get the power they need during high peak periods and, thus, face brownouts or blackouts. Second, if such a situation occurs, Congress or the administration could require that military bases with onbase power generating capacity either augment power from onbase generators or disconnect from the grid during times of peak demand. If not anticipated, this could be costly and disruptive to airbase operations, as has been observed at some Air Force bases where "peak power alerts," often called in the middle of the workday, disrupted and frustrated ongoing activities.[1] The revised Clean Air Act, recently passed by Congress (Reference 7) may exacerbate this situation by requiring greater reduction in the emissions from fossil fuel generating plants, especially in eastern and midwestern regions of the US, and may make some generating plants no longer economical to operate.

Many other cases of airbase energy dificulties could be cited; however, the point has been made. Probably the greatest difficulty faced by airbase energy managers is the urgent need to reduce the cost of energy products used by the base. Military budgets are substantially reduced, many bases will be closed, and operations at others will be reduced. Limited operations and maintenance (O&M) budgets and steadily increasing unit energy costs dictate that base energy consumption and associated costs be decreased to the absolute minimum to ensure adequate funds for other essential O&M activities.

2. National Energy Strategy and Senate Bill 3.41

In January 1991, the Bush administration issued a new national energy strategy to guide the formulation of national energy policies. Several years in development, this new strategy is the most recent effort to unify our nation under a single set of goals. The primary emphasis of the strategy is to reduce US dependence on foreign sources of oil by increasing domestic oil production, improving efficiency of motor vehicles, shifting vehicle fleets onto alternative fuels, and transferring other users of petroleum fuels to other energy sources such as natural gas, nuclear power, etc. A variety of methods are specified. Although recognized by many as the first significant effort to unify our nation with common energy goals and approaches, this strategy has been criticized by environmental groups opposed to some of the proposed approaches, such as opening the Arctic National Wildlife Preserve to oil exploration.

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[1]Personal communication, utility systems managers at Air Force Communications Command, Scott AFB, IL, August 1990.

Senate Bill 3.41, introduced in the US Senate early in February 1991 by Senators Johnston and Wallop, is intended to transform the administration's National Energy Strategy into law. Referred to as "The National Energy Security Act of 1991," it contains essentially the same elements as the National Energy Strategy, although each is couched in legislative language, which, when passed, will transform the elements into a directive under the law and authorize federal funding to support many of the directed activities. Senate Bill 3.41 has also been soundly criticized by environmental and other groups and will undoubtedly be substantially amended, if it should become law.

If passed, this law could become extremely important to MAJCOMs and airbase energy managers because it would provide numerous opportunities for obtaining federal funding to assist in procurement and installation of new, advanced energy systems, which could help reduce energy consumption and lower associated costs. For example, Senate Bill 3.41 specifies the replacement of diesel-fuel systems with renewable energy systems and authorizes funding for trial projects of this nature. MAJCOMs and airbases in the Pacific theater can formulate projects to exploit these opportunities and thus reduce their operating costs.

C. PROJECT APPROACH/SCOPE

Prediction of future airbase energy requirements through the year 2020 must consider AF mission system changes, energy product costs, changing worldwide circumstances relative to mission, energy security, and the environmental impact of energy product conversion. The technical approach followed in this project is depicted in Figure 1.

1. Current and Projected Airbase Energy Consumption

A comprehensive review of all energy consumed by all AF installations was beyond the scope of this project. Instead, a measure of airbase utility/energy consumption was attained by grouping representative AF installations into categories according to mission type, systems supported, location, size, etc. Data from the airbases in each category were evaluated. Past and current energy consumption trends for each category were estimated through mathematical and graphical analyses. A baseline of current facility/utility energy consumption and requirements was determined as follows:

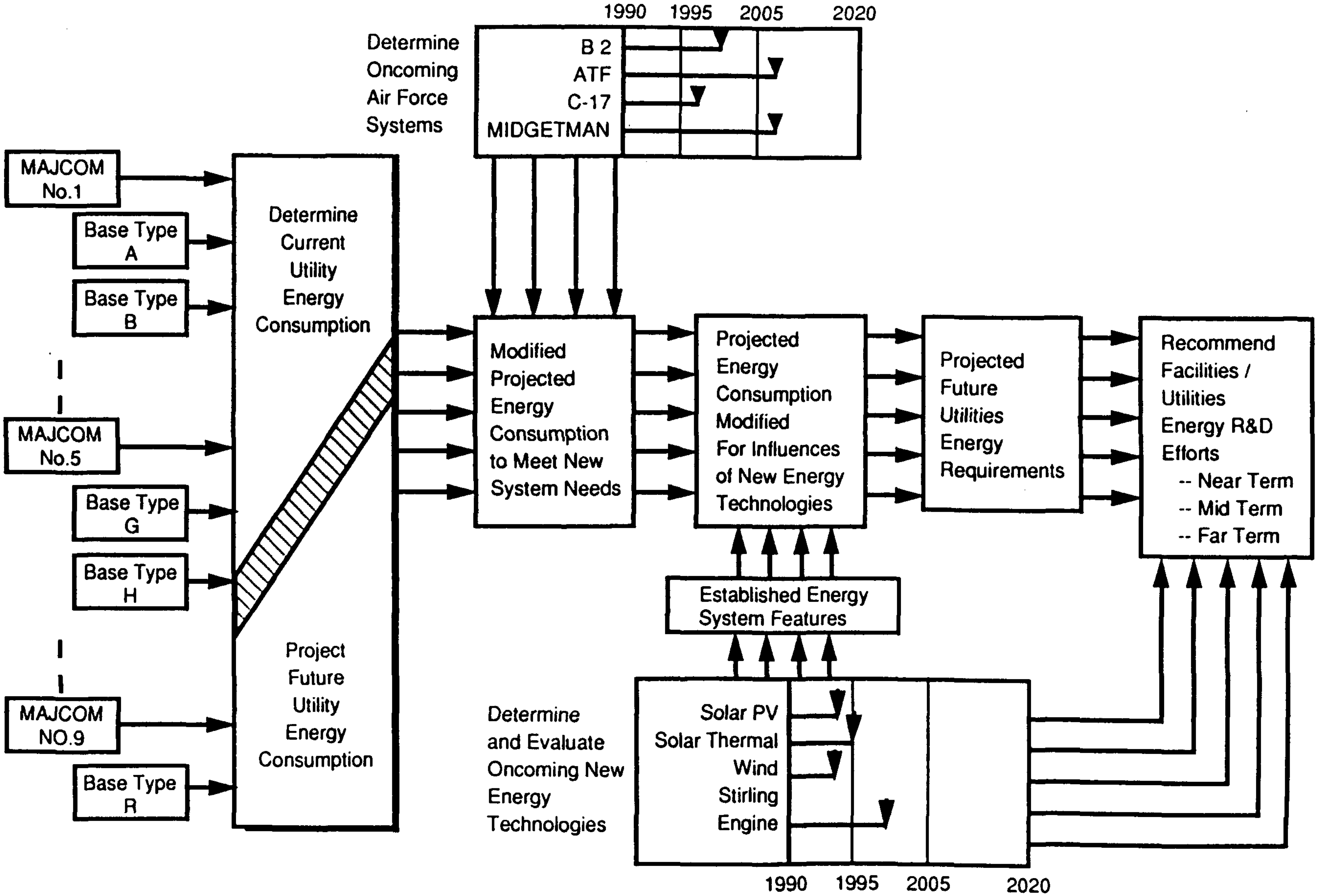


Figure 1. Project Plan for Facilities/Utilities Energy R&D Study.

a. Document Review. Reviews were done of (1) energy assessment work previously accomplished for AFESC/RDC by EG&G at the Idaho National Engineering Laboratory (INEL), as published in Air Force Engineering & Services Center Forecast Requirements Through 2020 (Sept 1989); (2) documents listed in Appendix A of the INEL report (provided by INEL through HQ AFESC); and (3) other applicable documents as required to establish the present status of energy requirements/capabilities.

b. Use Assessment. An assessment of airbase energy consumption data for the 1985-1989 time period was completed. Military base energy consumption data, stored in the Defense Energy Information System (DEIS II) database, have been entered into this service-wide system for the last 15 years. These data provided details on usage for the full range of energy products (electricity, natural gas, coal, solar, propane, etc.). Data entered after 1984 were readily available in the HQ AFESC/DEMM data storage system. Current requirements and trend analyses for the various airbase categories are determined for this recent consumption period.

c. Capabilities Analysis. A sampling of airbase energy and utility capabilities, summarized in the 1987 Oak Ridge National Laboratory study, Vulnerability Assessment of Energy and Utility Systems of 150 Air Force Bases — Summary, Methodology, Conclusions and Recommendations, was analyzed.

d. Energy Questionnaires. Questionnaires on airbase energy systems, consumption, requirements, and capabilities were constructed, sent to all AF airbases and MAJCOMS, and used as a reference document during personal interviews, telephone inquiries, and MAJCOM and airbase site visits to collect additional data on current and future requirements.

Estimates of future energy consumption were established by extrapolating these data for each airbase category, determining any recognizable trends, and projecting future energy requirements. This extrapolation, based on existing AF systems, in-place energy technologies, and current growth trends, served as a baseline for future requirements.

2. Impact of New Systems on Energy Requirements

AF Systems Command Laboratories and Product Divisions were contacted and onsite visits were made to identify new AF systems that might be deployed in the next 30 years. Individual system program managers were interviewed to the extent possible. Data collected and categorized in terms of near-, mid-, and far-term implementation were then further identified as to where and how each system might be based. Details regarding the facility/utility energy requirements for system implementations, modifications, or deletions were collected, entered into the database, and compared with the baseline projections estimated above.

3. Baseline of Energy Consumption and Projected Deficiencies

The projection of future energy requirements for the various airbase categories was compared with present airbase energy capabilities to define deficiencies. Existing infrastructures were examined to identify requirements for large-scale renewal. Factors such as geopolitical and national environmental issues sometimes influenced the projection of energy/utility supply needs.

4. Influence of New Energy Technologies on Energy Requirements

Many new energy technologies, currently under development, may mature within the next 30 years. Some could substantially influence AF utility/energy capabilities. These technologies have been examined with respect to technical feasibility and reliability, economic effectiveness, environmental compatibility, and political suitability. Furthermore, they have been reviewed with respect to potential application in solving the deficiencies identified in I.E. 3 above.

5. Recommended R&D Programs

The final result of this technical effort is the recommended prioritization of HQ AFESC/RDCE program emphases and suggestions for specific energy R&D efforts in the facility/utility energy areas.

SECTION II

POLICIES AND GUIDANCE RELATING TO AIRBASE ENERGY UTILIZATION

A. PREVIOUS ENERGY POLICIES AND GUIDANCE

Over the past 15 years many airbase energy-related policies, directives, regulations, and guidance documents have been issued (Reference 8). These have been used by airbase managers to improve energy system operations, achieve energy reduction goals, and ensure compliance with energy policies. A number of them are cited and/or summarized below.

1. Air Force Long-Range Conceptual Energy Plan (1985-2020),(Reference 9)

2. National Energy Conservation Policy Act, (NECPA).

3. Draft FY 1985-89 Defense Guidance, approved by Secretary Weinberger, 1 March 1983, Ch. 5, p. 98.

4. Defense Energy Program Memorandum, by R.D. Webster, OSD/DASD (L&MM), 12 Jan 1983.

5. Alternate Energy Sources, 1983, Air Force Logistics Research and Studies Program, pp. 4-245.

6. Facility Energy Policy, memo by Lt. Gen. Driessnack, USAF-AVCS, 20 Oct 1982.

7. Air Force Installations Energy Memo, by Tidal McCoy, ASAF (MRA&I), 30 Sept 1982.

8. Defense Energy Requirements Action Memorandum, by Hon. Verne Orr, SAF, 24 Sept 1982.

9. Defense Energy Requirements Draft Defense Policy Statement, by the JLC, 22 June 1982, and approved by Gen. Gabriel, CS-USAF.

10. Electrical Power Modernization, memos by Secretary Weinberger, 8 Dec 1981.

11. "Air Force Energy Management," Air Force Regulation (AFR) 18-1, 12 Aug 1987, (revised 25 Nov 1988).

    Defines the AF overall energy program (flying fuels, vehicle fuels, and facilities/utilities energy); identifies the organizations within the AF and DOD involved with this program and states the roles and responsibilities of each; establishes the AF Energy Program Policy Memorandum (AFEPPM) as the documentary vehicle through which energy information and guidance is issued; describes the Defense Energy Information System (DEIS) as the data reporting and storing system through which DOD determines progress in energy management; defines the Energy Budget Figure (EBF-MBtu/ft^2) as the measure of merit for energy management; and defines the categories of buildings in accounting for the floor area used in computing the EBF. An appendix provides values for converting quantities of fuel to Btus of energy.

12. "Air Force Energy Plan," Air Force Pamphlet (AFP) 18-5, 2 Oct 1987.

13. "Third-Party Financing," Air Force Energy Program Policy Memorandum (AFEPPM) 85-1 (Reference 10).

Third-party financing encompasses a variety of financing arrangements whereby private sector investment capital is placed into real property or equipment that provides specific services for a fee, which then amortizes the investment. By offering long-term contracts for energy procurement, government installations can provide potential investors with a firm energy market, which in turn allows the securing of capital for energy production projects. Simultaneously, such arrangements result in a secure supply of energy for the government installation at a potential price advantage relative to conventional energy supplies.

In recent years, considerable third-party activity has occurred in the development of energy production projects that supply energy to industrial and institutional sites, as well as several military installations. Most prominent has been the development of cogeneration and solid waste recovery projects to provide baseload steam supply and, in some instances, power supply for a specified contract period. Major activity in the development of third-party cogeneration projects has been spurred by the advent of legislation supporting cogeneration, tax incentives available for such projects, and the availability of low cost gas supplies.

AFEPPM 85-1 provides policy and guidance regarding third-party financed projects applicable to all levels of command. The policy states that third-party financing should be "vigorously pursued" on a competitive basis with the MCP to improve energy security and efficiency. It further requires that all MCP submittals include a life-cycle cost assessment of third-party alternatives.

Third-party financed energy production projects could include both utility-owned and third-party owned and operated cogeneration plants, solid waste recovery facilities, process energy plants, solar thermal electric generating plants, and wind farms.

14. "Energy Management Monetary Awards Program," AFEPPM 86-2.

Essentially updates AFEPPM 84-4. Establishes an Energy Management Monetary Awards Program that encourages MAJCOMs to return a portion of any energy savings (O&M funds) to the generating air base and to present energy savings awards at appropriate ceremonies. Offers suggested approach for operating such a program and for selecting winners.

15. "Facility Energy Conversion," Air Force Energy Program Policy Memorandum AFEPPM 86-6 (Reference 11).

This AFEPPM establishes energy conversion goals for the period 1 October 1985 through 30 September 1995. It rescinds AFEPPM 80-2, as is pertains to solid fuel conversion and alternative energy sources. It provides the following long-range conversion goals:

- Achieve a 10 percent reduction in the use of natural petroleum fuels from 1985 baseline levels primarily through solid fuel conversions and the use of alternative energy sources by 1995.

- Obtain 20 percent of total installation energy from coal (including solid coal, coal liquids, and coal gas), municipal solid wastes, alternative fuels, and wood by 1995.
- Obtain 5 percent of total installation energy from geothermal and renewable energy sources utilizing the following technology applications by 1995: geothermal heating and electric; low head hydropower; solar heating and cooling; solar electric; biomass (waste-to-energy recovery and wood); wind; and ocean thermal.
- Meet or exceed established energy consumption criteria for all new facility designs or substantial renovation projects, regardless of construction funding, source, or method of accomplishment.
- Projects responsive to requirements stated in AFEPPM 86-6 include cogeneration, solar heating and electricity generation, waste-to-energy recovery, thermal energy recovery, and energy conservation improvements relating to onsite heating, cooling, and process systems.

16. "Facility Energy Metering," AFEPPM 86-7

17. "Defense Energy Information System-Utility Energy Report," AFEPPM 86-8
Provides policies and procedures that place all Defense Energy Information System-Utility Energy Report (DEIS-II) data into a single reference document for installation, major commands, and air staff facility energy managers; and implements Defense Energy Programs Policy Memorandum (DEPPM) 86-4.

18. "Energy Security in Air Force Facilities," AFEPPM 86-14
This AFEPPM implements DoD planning guidance and energy program management goals and establishes policy for energy security on Air Force installations. It rescinds AFEPPM 85-2 pertaining to energy security. It calls for onsite cogeneration and other power generation facilities, improvements to existing onsite electric systems to increase service reliability, and offsite and onsite additions to airbase fuel systems to enhance supply redundancy.

19. "Building Energy Technical Surveys," AFEPPM 86-16
This AFEPPM implements the intent of the national Energy Conservation Policy Act (NECPA) and DoD memorandum concerning energy programs management by establishing AF policy for building energy technical surveys.

20. "Building Temperature Standards," AFEPPM 88-8
This AFEPPM implements DoD intent regarding heating and cooling of living and working spaces and establishes AF policy concerning building temperature standards. It rescinds AFEPPM 81-8 pertaining to building temperature restrictions.

21. "Facility Energy Life Cycle cost Analysis Criteria," AFEPPM 88-9
This AFEPPM provides AF policy on facility energy Life-Cycle Cost Analysis (LCCA) criteria that will be used for all facility energy projects.

22. "Energy Reporting," AFEPPM 90-2

23. "Energy Efficient Equipment," Engineering Technical Letter (ETL) 82-2

24. "Computer Energy Analysis," ETL 84-2

25. "Energy Conservation Investment Program (ECIP)," ETL 84-7

26. "Energy Management and Control Systems (EMCS)," ETL 86-2

27. "Solar Applications," ETL 86-14

28. "Energy Budget Figures," ETL 87-A

29. "Utility Meters," ETL 87-5

B. RECENT ENERGY POLICIES AND GUIDANCE

"DOD Energy Management Goals for the 1990s," Memorandum for Secretaries of the Military Departments and Directors of Defense Agencies, Defense Secretary Cheney, 1991. This recent facilities energy directive sets further, more stringent energy reduction goals for military bases, defines strategies for achieving these goals, emphasizes environmental compliance, and mandates changes in the ways that military base energy managers conduct and report military facilities energy business. Portions of the directive are presented in the following paragraphs.

Findings. Energy is critical to the Defense mission. The use of energy directly affects the productivity as well as quality of life and working conditions of Defense personnel. Energy production, distribution, and use also impact the quality of our environment. Sound energy management is essential to assuring adequate energy is available at minimum cost and with the least environmental impact.

Policy. The DOD will lead in energy resource management, while providing quality mission support and working and living conditions for Defense personnel and their families.

Goals. *Energy Use Reduction in Administrative and Similar Buildings.* Each DOD Component will prescribe policies and implement programs to reduce the energy used in these buildings for the years 1991 through 2000. This reduction shall be at least 20 percent as compared to FY 85, measured in Btu per gross square foot, to be fully achieved no later than FY 2000. This goal will apply to leased facilities, except when determined infeasible by Component heads.

Industrial-Type Facilities. Each DOD Component will prescribe policies and implement programs under which its industrial, energy-consuming facilities improve their gross energy efficiency by 20 percent by FY 2000 vs FY 85.

Strategies for Implementing Goals. Each DOD Component will develop a plan to accomplish the assigned goals. The plan, detailing activities in the following areas, shall be submitted to the Office of the Asst. Secy. of Defense for Production and Logistics, OASD(P&L), by Apr 30, 1991.

Improved Operations and Maintenance. Each DOD Component will improve facilities and energy systems operations, maintenance, and related training to increase efficiency in the production and use of energy.

Capital Investment. DOD Components will identify and program for funding energy conservation projects of military construction scope with simple paybacks of 10 years or less, as well as those projects appropriate for O and M type funding with rapid payback, in order to meet the program goals. Detailed guidance on project prioritization and programming will be provided by OASD(P&L).

Public Utility Programs. DOD Component installations will participate in electricity demand side management (DSM) and conservation programs when and where such programs are offered by regulated public utilities. Installations should be encouraged to take immediate advantage of such programs where available. The Secy. of the Army will coordinate with the Secretaries of the Navy and AF and with the heads of Defense Agencies to develop and submit an integrated strategy for all Components within the services territory of each utility to the OASD(P&L), by Sept 1, 1991.

Shared Energy Savings Contracting (42 USC 8287). Each Military Dept. will initiate a minimum of three shared energy savings contracts per year, beginning in FY 91. DOD Components are authorized by 10 USC 2865 to conduct direct negotiations of shared energy savings contracts with firms that have been competitively selected and approved by the utility company serving a defense facility. The Secy. of the Navy, in coordination with the Secretaries of the Army and the Air Force and the Heads of the Defense Agencies, will take the lead to develop a simplified contracting process, including contractor prequalification standards and selection procedures, in accordance with 10 USC 2865.

Lighting Systems. The Director, Defense Logistics Agency, will coordinate with the Military Services, the General Services Administration, DOE (Federal Energy Management Program Office), lighting equipment manufacturers and others, as needed, to improve the quality of information available to federal managers on selecting efficient lighting systems and equipment. A plan for development and dissemination of appropriate guidance for replacement equipment selection at the installation level will be reported to OASD (P&L) by May 20, 1991.

Alternative, Renewable, and Clean Energy. DOD Components will use alternative, renewable, and clean energy sources wherever such use is cost effective over the life of the facility. All components are encouraged to participate in demonstration programs of DOE when cost effective and compatible with installation mission. The Secy. of the Army shall coordinate with the Secretaries of the Navy and the Air Force and, as needed, with the Heads of Defense Agencies, in the development of strategies for use, and of the energy sources, with the exception of solar and geothermal energy. The Secy. of the Navy shall be the lead in solar and geothermal technology application and resource development.

Use of Coal. Congress has annually directed DOD to increase the use of coal at its installation in the US by 1.6 million tons/year in FY 94, as compared to 1985. Statute (10 USC 2590) also requires that new energy systems use the lowest life cycle cost fuel. Each Component will establish plans to increase its use of coal to the maximum extent possible by FY 94, consistent with 10 USC 2690. The Secy. of the Army will coordinate with the Secretaries of the Navy and the Air Force, as required, to develop a coordinated Defense plan and to provide the OASD(P&L) with an update on progress toward meeting this goal by June 1, 1991.

Environment. *Environmental Compliance and Least Costing Planning.* Conservation and energy efficiency improvements will be consistent with environmental statutes and regulations. In addition, particular attention should be directed to actions that achieve environmental compliance through conservation at a least combined cost. Until a DOD standard methodology exists, each Component head will prescribe means by which the energy impacts of meeting environmental quality goals, such as chlorofluorocarbon (CFC) replacement, will be measured and energy conservation efforts to minimize these impacts evaluated.

Environmental Benefits of Conservation. The environmental benefits of conservation actions, such as reduced CO, CO_2, SO_x or NO_x emissions, will also be measured. The Secy. of the Air Force will coordinate with the Secretaries of the Army and Navy and the Heads of Defense Agencies, as required, to develop a coordinated, auditable measurement method. To the extent permitted by law and regulation, the method should address the potential for exchanging or trading benefits. Components will establish focal points for this coordination process by April 20, 1991.

Retention and Use of Savings. Congress has provided financial incentives for increased energy conservation by granting authority to retain and reuse energy cost savings. Component heads will direct their subordinate organizations to comply with these provisions in a way that assures savings retention and continuing incentives for energy conservation at the installation level. Specific provisions to be implemented include (1) *Section 736 of PL 100-456 (1988) as amended by section 331 of PL 101-189 (1989)* concerning measurement, retention and use of savings from shared energy savings contracts; and (2) *10 USC 2865* with respect to retention and use of savings from energy conservation projects generally.

Progress and Reports. DOD Components will report their aggregate facility energy use quarterly and provide a narrative report and specific data to support progress toward the goals listed above, to the OASD (P&L) no later than April 15 of each year, beginning in 1991. DOD 5146.47, Defense Energy Information System (RCS: DD[P&L-AR 1313]) governs this report.

"Federal Energy Management," Executive Order. President Bush, 17 Apr 1991. This most recent federal order imposes new, very stringent requirements for facilities energy reductions and for the use of alternative fuels in fleet vehicles on all departments and agencies of the federal government. Major portions of the document are abstracted below.

Section 1. Federal Energy Efficiency Goals for Buildings. Each agency shall develop and implement a plan to meet the 1995 energy management goals of the National Energy Conservation Policy Act, as amended, 42 USC *** et sec., and by the year 2000 reduce overall energy use of Btus per gross square foot of the federal buildings it operates, taking into account utilization, by 20 percent from 1985 energy use levels, to the extent that these measures minimize life cycle costs and are cost-effective in accordance with 10 CFR Part 426.

Section 2. Federal Energy Efficiency Goals for Other Facilities. Each agency will prescribe policies under which its industrial facilities in the aggregate increase energy efficiency by at least 20 percent in FY 2000 in comparison to FY 85, to the extent that these measures minimize life cycle costs and are cost-effective in accordance with 10 CFR Part 426. Each agency shall establish appropriate indicators of energy efficiency to comply with this section.

Section 3. Minimization of Petroleum Use in Federal Facilities. Each agency using petroleum products for facilities operations or building purposes shall seek to minimize such use through switching to an alternative energy source, if it is estimated to minimize life cycle costs and which will not violate federal, state, or local clean air standards. In addition, each agency shall survey its buildings and facilities to determine where the potential for a dual fuel capability exists and shall provide dual fuel capability where practicable.

Section 4. Implementation Strategies. (a) Except as provided by paragraphs (b) and (c) of this section, each agency shall adopt an implementation strategy, consistent with the provisions of this order, to achieve the goals established in Sec. 1, 2, and 3. That strategy should include, but not be limited to, changes in procurement practices, acquisition of real property, participation in demand side management services and shared savings agreements offered by private firms, and investment in energy efficiency measures. The mix and balance among such measures shall be established in a manner most suitable to the available resources and particular circumstances in each agency. (b) The Secretary of Defense may, if he determines it to be in the national interest, issue regulations exempting from compliance with the requirements of this order, any weapons, equipment, aircraft, vehicles, or other classes or categories of real or personal property, which are owned or operated by the U.S. Armed Forces (including the Coast Guard) or by the National Guard of any State and which are uniquely military in nature. (c) The Secretary of the Treasury and the Attorney General, consistent with their protective and law enforcement responsibilities, shall determine the extent to which the requirements of this order shall apply to the protective and law enforcement activities of their respective agencies.

Section 5. Procurement of Energy Efficient Goods and Products. In order to assure the purchase of energy efficient goods and products, each agency shall select for procurement those energy consuming goods or products which are the most life cycle cost-effective, pursuant to the requirements of the Federal Acquisition Regulation. To the extent practicable, each agency shall require vendors of goods to provide appropriate data that can be used to assess the life cycle costs of each goods or product, including building energy system components, lighting systems, office equipment, and other energy using equipment.

Section 6. Participation in Demand Side Management Services. Each agency shall review its procedures used to acquire utility and other related services, and to the extent practicable and consistent with its strategy established pursuant to Section 4, remove any impediments to receiving, utilizing, and taking demand side management services, incentives, and rebates offered by utilities and other private sector energy service providers.

Section 7. Energy Efficiency Requirement for Current Federal Building Space. Each agency occupying space in federal buildings shall implement the applicable rules and regulations regarding federal property and energy management.

Section 8. Energy Efficiency Requirements for Newly Constructed Federal Buildings. Each agency responsible for the construction of a new federal building shall ensure that the building is designed and constructed to comply with the energy performance standards applicable to Federal residential and commercial buildings as set forth in 10 CFR, Part 435. Each agency shall establish certification procedures to implement this requirement.

Section 9. Vehicle Fuel Efficiency Outreach Programs. Each agency shall implement outreach programs including, but not limited to, ride sharing and employee awareness programs to reduce the petroleum fuel usage by federal employees and by contractor employees at government-owned, contractor-operated facilities.

Section 10. Federal Vehicle Fuel Efficiency. Consistent with its mission requirements, each agency operating 200 or more commercially designed motor vehicles domestically shall develop a plan to reduce motor vehicle gasoline and diesel consumptions by at least 10 percent by 1995 in comparison with FY 91. The Administrator of General Services, in consultation with the Secretary of Energy, shall issue appropriate guidance to assist agencies in meeting this goal.

SECTION III
WORLD ENERGY STATUS

A. INTERNATIONAL ENERGY STATUS[1]

A number of highly-regarded, world-class organizations perform frequent and comprehensive reviews of the world energy situation and its potential effects on world populations (Reference 12, p. 108). Recent projections by several of these sources forecast an increasing energy squeeze in the coming years. The world population continues to increase rapidly, the per capita consumption of energy is expanding for all nations, the available supplies of common fuels are decreasing, and environmental effects linked to nearly all currently used energy sources are beginning to restrict the amount and the manner in which fuels are consumed.

The world population consumes energy at the rate of 10 billion kilowatts (kW) per hour, which represents more than 2 kW of power for each of the 5 billion men, women, and children on earth. The individual 2-kW share is the same as the power consumed by 20 constantly illuminated 100-watt light bulbs. Not all people share equally in this bounty of power (Table 1). In the United States, for example, the rate per person is 11 kW, while in India it is about 0.2 kW. The later figure is probably close to the world average at the time of the American Revolutionary War (1775-1783). So, while the global consumption of energy has grown tremendously in about 200 years, India still has a long way to go, as does the balance of the Third World. As developing countries acquire more factories, farm machinery, and transportation facilities, their rate of energy use per person will increase rapidly. Furthermore, the population of the Third World is growing so quickly that it may double by the year 2020; thus, the total amount of energy consumed by developing countries is bound to soar (Figure 2).

All of the world's energy originally comes from the sun or from terrestrial sources (Figure 3). More than 91 percent of the world's energy derives from burning fossil fuels (Figure 4). Another 6 percent comes from burning fuels, mainly wood and animal wastes. The remaining 3 percent comes from such sources as hydroelectric dams, nuclear power plants, and solar devices. The largest current single component of this 3 percent — hydroelectric power —

[1]Portions of this section have been adapted from The 1990 World Book Year Book, the annual supplement to the World Book Encyclopedia (World Book Publishing, 525 W. Monroe St., Chicago, IL 60606).

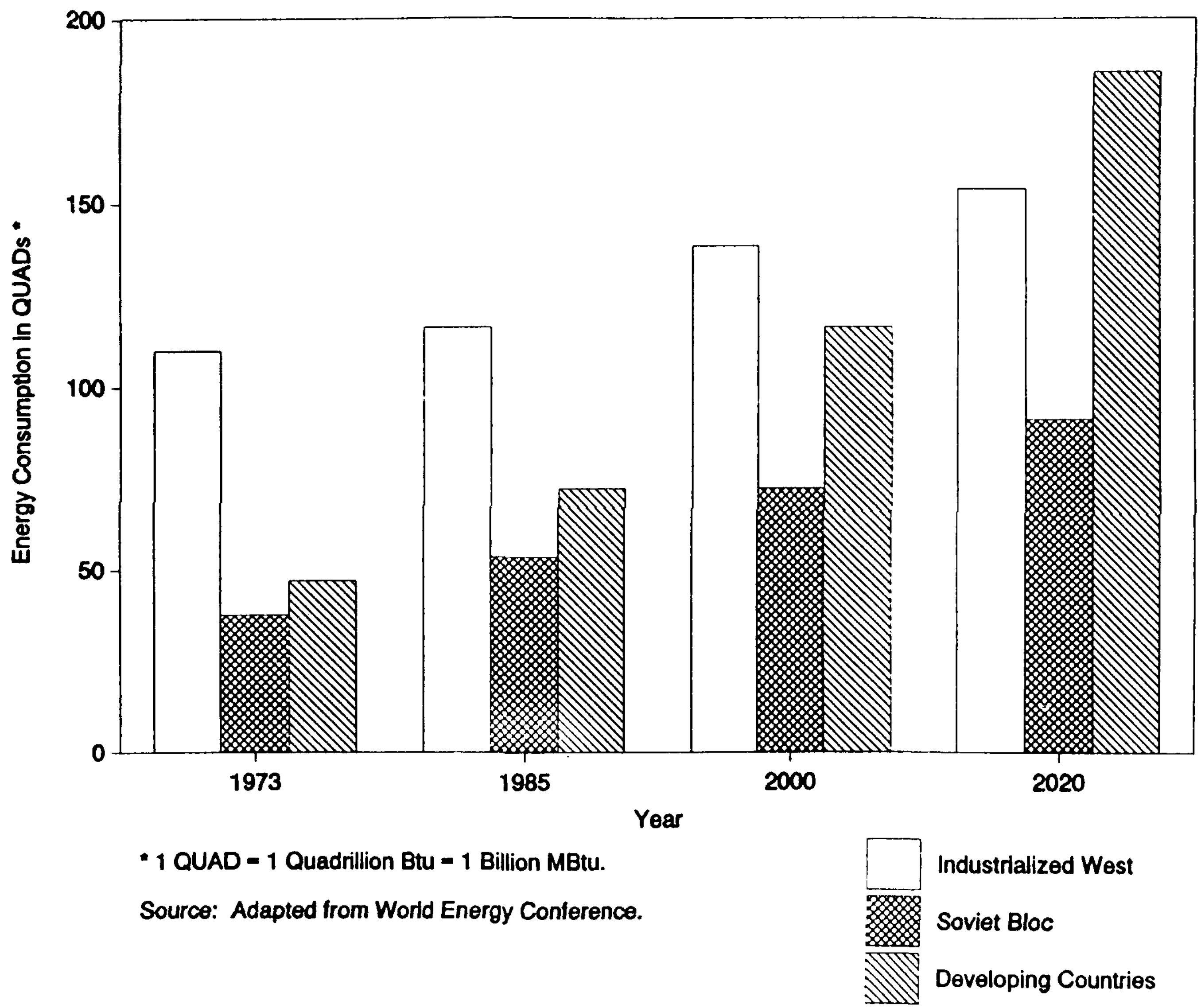
TABLE 1. ANNUAL CONSUMPTION OF ENERGY PER CAPITA.

Country	Estimates in millions of MBtus/yr
Canada	277
United States	227
The Netherlands	154
West Germany	151
Great Britain	120
France	116
Japan	98

will soon reach the limit of its potential. Most of the best sites for power dams have already been developed. Many people view the second largest component — nuclear fission — as too risky and the remaining sources as either having too little potential or being too expensive at their present state of development.

The world's known reserves of fossil fuels are limited and are being consumed at an alarming rate. Figure 5 shows that at current rates of consumption and known reserves, the world will run out of oil by the year 2025 — 34 years from now! New discoveries of oil might extend this time but not by very much. If these estimates hold, children born today will have petroleum fuels available for only a third of their lives and natural gas for about two-thirds. Coal will be available for perhaps two generations beyond that. And, as will be discussed in the following paragraphs, fossil fuels carry increasing environmental complications.

Despite tremendous resistance to its use in the United States, nuclear fission remains a steadily growing source of energy in many parts of the world. Several European nations depend heavily on nuclear power for a large portion of their nation's energy. The amount of world energy supplied by nuclear power is projected to grow steadily over the next 30 years (Figure 6). To many people, the risks of nuclear power outweigh the gains — despite the good safety record. When asked what they would put in its place, most point to the sun. At first glance, solar energy is an inviting prospect. Every day, the sun delivers to our planet 20,000 times as much energy as we use. The world utilization of renewable energies is increasing steadily and expected to double over the next 30 years (Figure 7).



* 1 QUAD = 1 Quadrillion Btu = 1 Billion MBtu.

Source: Adapted from World Energy Conference.

Figure 2. Total World Energy Consumption — A Growing Demand.

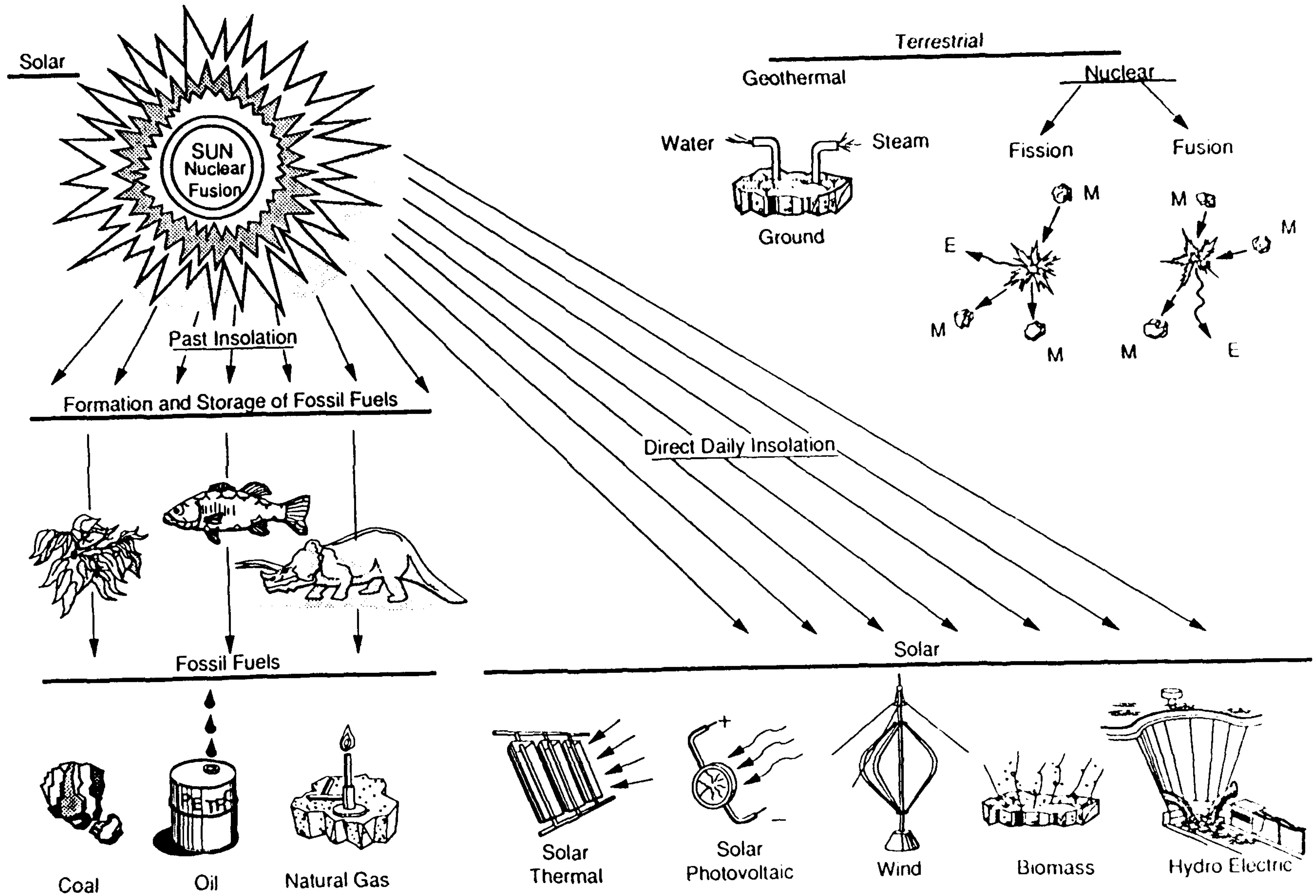
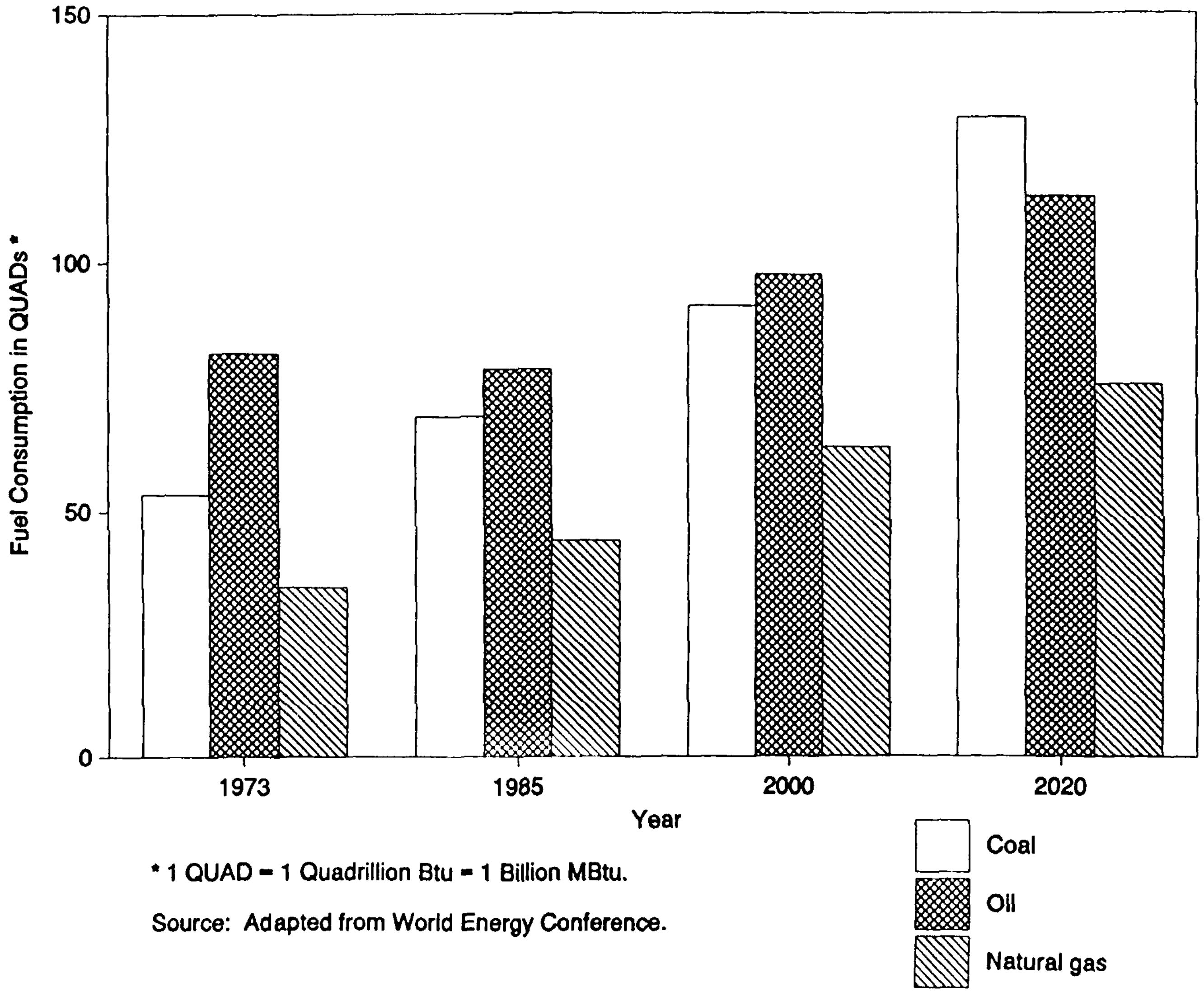


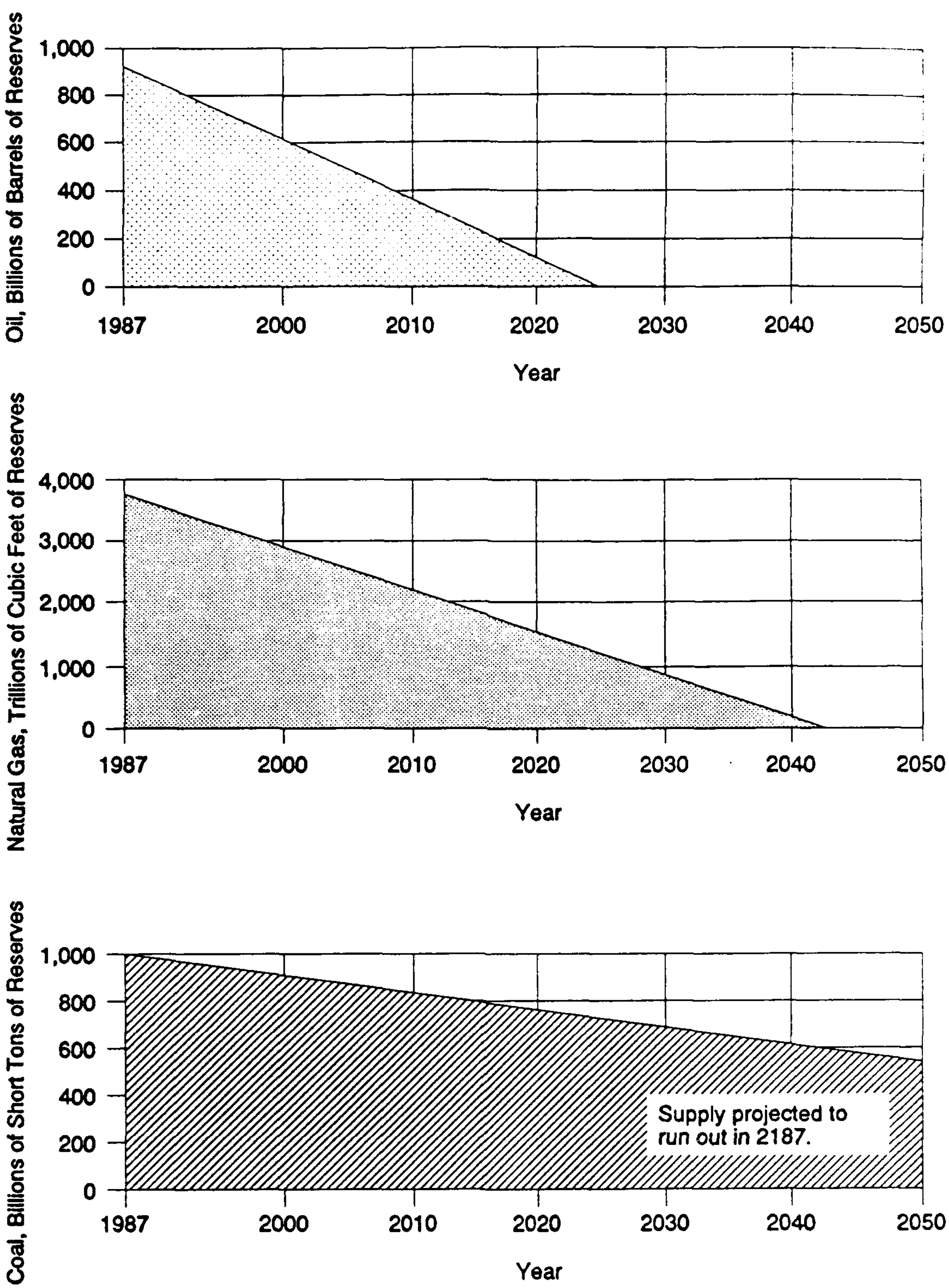
Figure 3. Sources of Usable Energy.



* 1 QUAD = 1 Quadrillion Btu = 1 Billion MBtu.

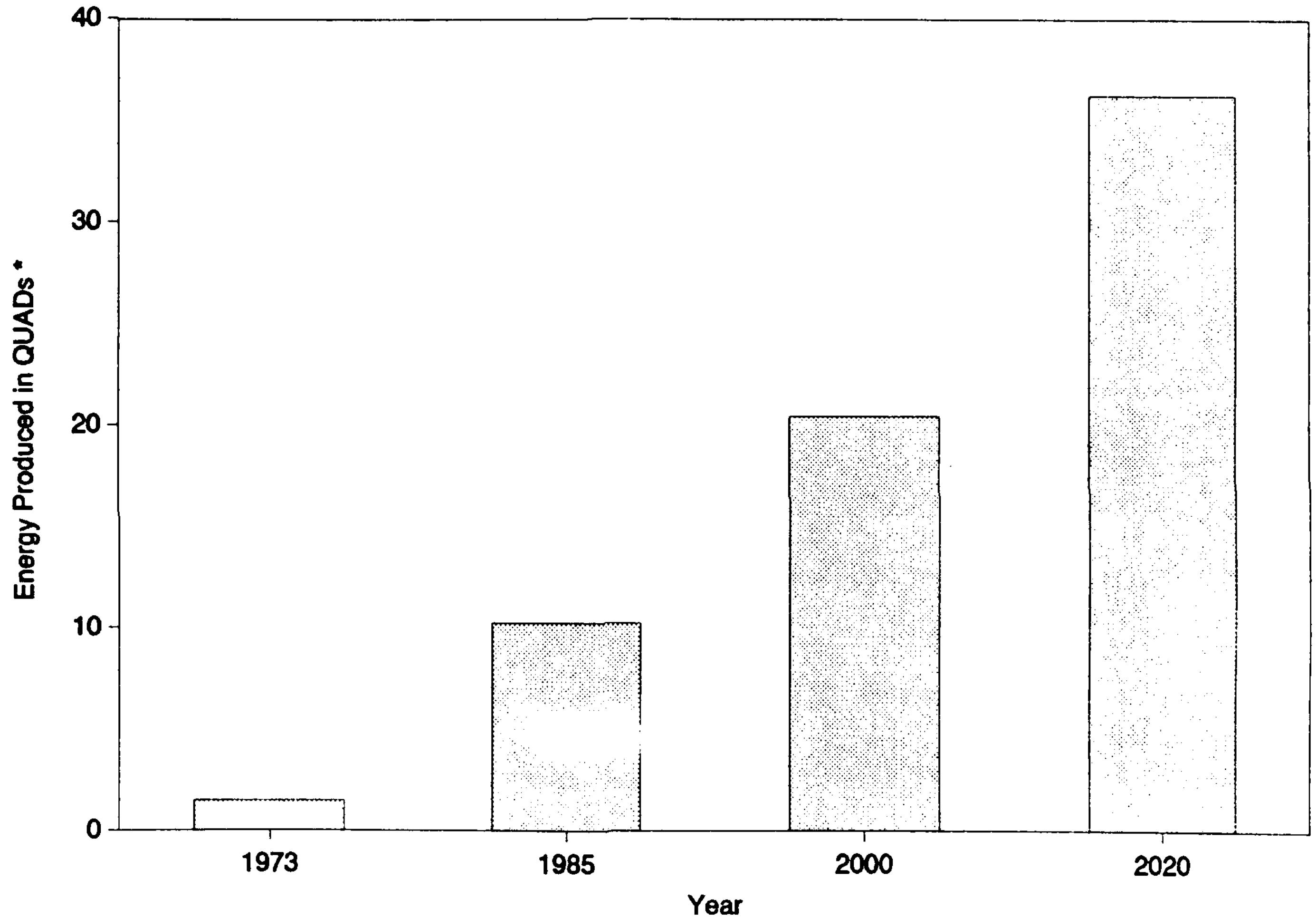
Source: Adapted from World Energy Conference.

Figure 4. World Consumption of Fossil Fuels.



Source: Adapted from U.S. Department of Energy.

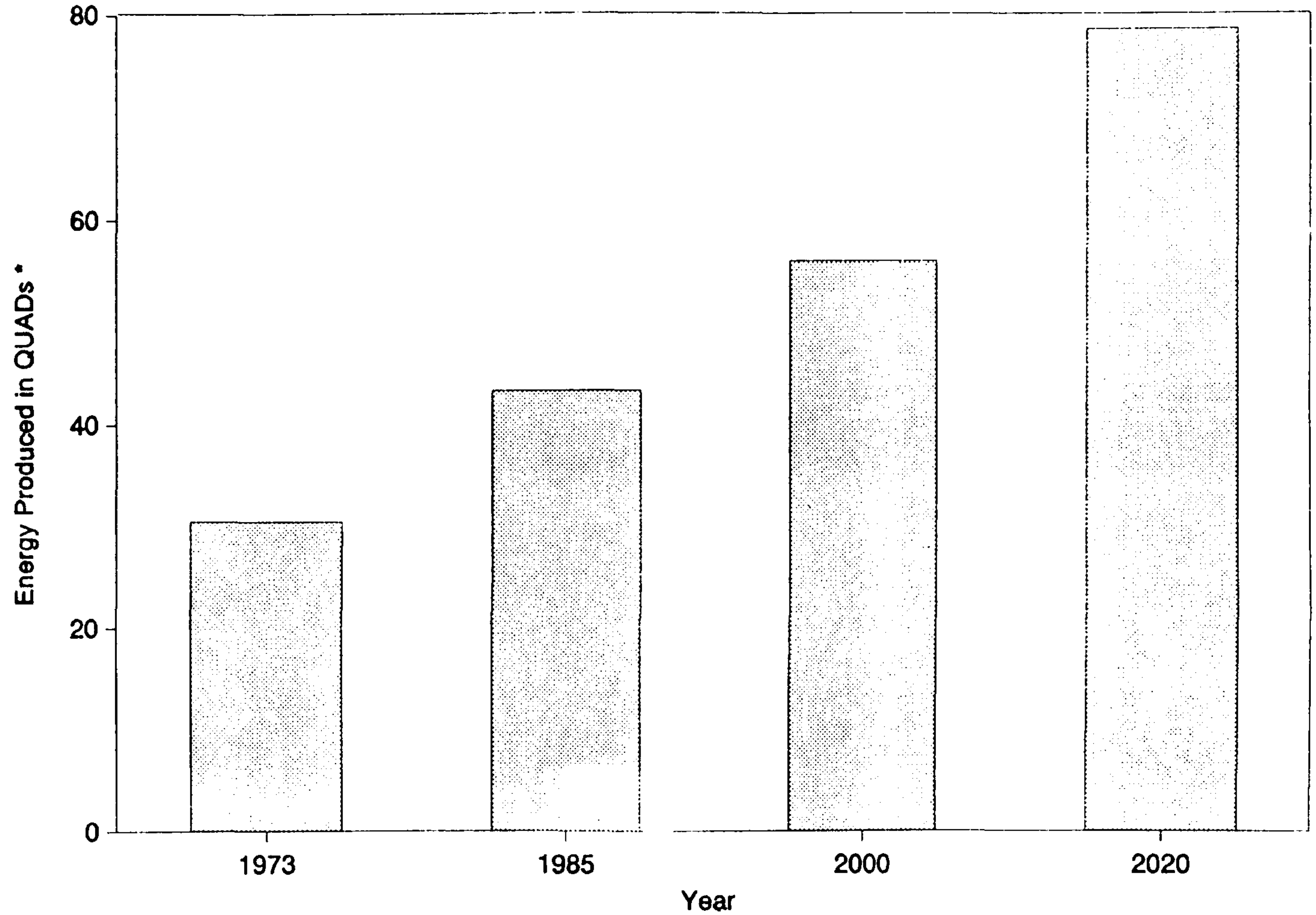
Figure 5. Dwindling Fossil Fuels.



* 1 QUAD = 1 Quadrillion Btu = 1 Billion MBtu.

Source: Adapted from World Energy Conference.

Figure 6. Projected Contribution to World Energy from Nuclear Fission.



* 1 QUAD = 1 Quadrillion Btu = 1 Billion MBtu.

Renewable sources include hydroelectric, solar, and geothermal energy, winds, ocean tides, waves, fuel wood, and animal and vegetable wastes.

Source: Adapted from World Energy Conference.

Figure 7. Projected Contribution to World Energy from Renewable Sources.

Solar energy presents two problems: availability of sufficient amounts where and when it is needed and lack of concentration. Each year, enough sunlight falls on the roof of a typical US family home to meet all its energy needs, even if only 25 percent of the energy in the sunlight were converted into a usable form, such as electricity. However, with low levels of sunlight in the winter months and none at night, much of the energy collected during summer days would have to be stored. At present, there are few cost-effective ways to store it.

Even if there were such a way, there might not be enough solar energy to store. In the middle of the brightest day, the concentration of sunlight is so low that it is generally cheaper to buy gas for heating and electricity for lighting than it is to generate energy from sunlight at home. Solar cells that convert sunlight to electricity cost 5 to 10 times as much as a nuclear power plant per kilowatt of power, when both the cells and the plant are producing as much power as they can. Furthermore, over the course of a year, a nuclear plant can average about 60 percent of its maximum power, while at most locations it would be unusual for a solar cell to average 15 percent.

Research is ongoing to develop cheaper devices that can convert sunlight to usable amounts of electricity. If these efforts are successful, solar power could provide a significant percentage of our electricity; in the foreseeable future it is not likely to meet a large fraction of our energy needs. People in some locations can obtain usable amounts of energy from winds, tides, or geothermal energy. Wind power is practical only in areas that have strong, steady winds. In California, for example, there are more than 15,000 wind turbines, with a combined output of 1.5 million kW, enough electricity to meet the needs of 750,000 households.

The only locations where tidal energy can be tapped economically are bays that are penetrated by high tides and that can be closed off by a dam. During high tide, the bay fills with water. During low tide, the ocean level drops below the level of the water stored behind the dam. The stored water is then released and, as it falls, it drives turbines that generate electricity. The first tidal power plant was built in 1966 on the Rance River near St. Malo, France, to produce 544 million kW of electricity each year.

Geothermal energy is relatively cheap only when sources of intense heat are available near the surface of the earth or at shallow enough levels to make it practical to drill down to the sources. So far, Italy, Japan, the Philippines, the United States, and other nations have built about 130 geothermal power plants with a combined capacity of 2 million kW. In addition, several countries use geothermal heat directly to heat buildings. Water from hot springs, for example, heats all the buildings in Reykjavik, the capital and largest city of Iceland.

An experimental technique know as Ocean Thermal Energy Conversion uses the difference in temperature between warm surface water and cool, deep water to drive turbines. In the United States, coastal waters of the Gulf of Mexico and off southern California may be the only locations with sufficient differences in water temperatures to make this type of power available at an affordable cost.

As a result of all these limitations, the winds, the tides, and geothermal and ocean heat are unlikely to provide more than a few percent of the world's energy needs in the foreseeable future.

There are many things the world can do to buy more time to search for and develop new energy sources. The most important of these is to conserve the sources that we already have. Although the energy crisis of the 1970s forced Americans to conserve fuels, the US still uses much more energy than it really needs, partly because, until recently, its own domestic reserves were cheap and plentiful. Western Europe and Japan, not so favored by nature, have managed to match the US standard of living, while using about half as much energy per inhabitant. A well-planned effort to improve the energy efficiency of transportation, industry, and home heating and cooling systems could help the US economy by reducing energy imports and the cost of manufacturing, while minimizing damage to the environment. This effort is already underway. New factories and homes, for example, are generally much more energy-efficient than the ones they are replacing.

On the supply side, a multifaceted approach will have to do. Although energy from the sun, wind, tides, and volcanoes may never be the final answer, these sources can supply an increasing share of the world's energy needs. And as supplies of fossil fuels begin to run out, their price is bound to rise, favoring energy sources such as solar cells that now seem too expensive. Even at present rates of consumption, petroleum supplies may be exhausted early in the next century, natural gas in mid-century, and coal by 2200.

Although science has no instant solutions to our world energy problems, it does give us many ways to manage the continuing energy crisis while reducing the stress on our environment. This "nickel-and-dime" approach may not have the glamour of a scientific breakthrough, but it can work.

B. UNITED STATES ENERGY STATUS

1. Historical Perspective

The history of the growth and industrial development of America is nearly parallel to the history of energy consumption. Until the 1960s, there appeared to be no significant effects from the ever-increasing energy consumption, and there was little public awareness of or concern for environmental consequences. Even in 1973, the supply of all forms of energy appeared to be limitless and sufficiently inexpensive as to encourage greater and greater use for all conceivable purposes. Nuclear power seemed to be an inexhaustible source of low-cost power, and there was little concern for nuclear safety and radiation problems.

The OPEC oil embargo in 1973 brought a sudden and shocking recognition that supplies of some forms of energy were limited, and that we could not continue to increase the consumption of energy. Additionally, some environmental consequences of our rate and manner of energy consumption began to be recognized.

Since then, significant energy conservation efforts have been implemented, and the development of new technologies for energy production and environmental improvement has been initiated. Yet, consumption continues to grow and adverse environmental consequences are becoming increasingly apparent.

2. Major Types of Energy

a. Fossil Fuels (in general)

An increasingly strong influence from a concerned citizenry is urging the conservation of energy, a reduction in the consumption of fossil fuels, and a switch to less environmentally damaging sources of energy.

Several incidents over the past few years have served to arouse a great many people in the US, if not the entire world, and have brought forth a new level of concern regarding the long-term environmental effects of many of our past and current energy practices. The "greenhouse effect" is becoming a more widely accepted scientific theory (Reference 13). Because the world appears to be warming at twice the rate projected and our climate seems to be affected, environmentalists are becoming increasingly alarmed (References 14-17). Concerns about acid rain, the recently discovered hole in the ozone layer, the huge oil spill near Valdez (Alaska), and many other events and issues have all led to a new awareness by the citizenry, who are likely to begin exerting even more pressure to change the way that we utilize our many energy sources (References 18 and 9). This pressure, exerted through Congress and the federal government, could substantially change the way that energy and power are provided to airbases and other installations over the next 30 years. Large reductions in the consumption of fossil fuels could be mandated. Nationwide production of chlorofluorocarbons (refrigerants, halons) is restricted under the Montreal Protocol (1987), and further restrictions are likely. Airbase energy managers may be required to adopt or develop new, more environmentally safe approaches for providing heat and power.

b. Petroleum

Known US petroleum reserves are dwindling (References 6, p. 50, and 20). Because of the low prices for foreign crude oil, investments in new US drilling efforts have declined (References 20, pp. 59-60, 584-593, and 21, 22, 23). Consequently, domestic dependency on foreign sources of crude oil will continue far into the foreseeable future. Unless some remarkable new source of oil is discovered, the price for crude oil will climb steadily back to and then exceed pre-1986 price levels. Worldwide competition for available petroleum reserves has already led to international conflicts and the use of force. This trend could have a major influence on airbase energy activities over the next 30 years. Although military use comprises only a small fraction (approximately 3 percent) of the national consumption of petroleum products, many of the Pacific Air Forces (PACAF) airbases are very dependent on petroleum fuels.

c. Natural Gas

There is, and will continue to be, a reliable supply of natural gas within the continental US over the next 30 years. Proven reserves of natural gas are substantial and more than adequate to meet projected domestic consumption for more than the next 50 years (References 6, p. 119, and 24). These reserves should preclude any immediate shortages of natural gas and prevent dramatic escalations in cost. However, the cost of natural gas is likely to increase steadily. Natural gas is also a more environmentally compatible fuel than coal. It emits less pollution and is more suitable for cogeneration and distributed energy systems. These and other advantages in the use of natural gas will continue to encourage the shift from other fuels where possible, some of which have already occurred. Over the next 30 years, the availability and affordability of natural gas should have little affect on airbases because natural gas is already used in most locations where it is readily available. Shifts to increased use of natural gas to reduce electric power loads could occur.

d. Coal

Coal reserves in the US are sufficient to provide total national energy requirements for over 100 years. Coal accounts for about 80 percent of the proven recoverable fossil fuel reserves in the US (Reference 20, p. 5). In 1986, 57 percent of all electricity produced was generated by coal (Reference 6, p. 149). The use of coal, especially in the public utility sector, is projected to increase 25 percent by 1995. As discussed in Section I, recently enacted congressional and DOD policies urge the conversion to and greater use of coal for military installations.

e. Electricity

The demand for electric power throughout the US continues to increase while the number and capacity of generating plants available for providing this power are decreasing. This situation will lead to major shortages of power within the next 10 years (Reference 6, p. 116). The standard of living in the US is becoming increasingly dependent on electrical power. Each year more devices that use electricity are purchased by the public and are used for longer periods of time (Reference 25). This fact, along with the steady growth in the population, has led to a steadily increasing demand for electrical power (currently escalating at about 3 percent per year) (References 6, p. 137, and 21, p. 21). At the same time, the number of major power plants available to provide this power is decreasing (References 6, p. 139, and 26, 27). Utility regulations, unrewarding rate structures and new environmental constraints are discouraging new capital investments (References 6, p. 21, 21, pp. 130-131, and 26, 28). Very few new plants are planned or being built, and some older ones are being shut down because of age and high costs for operation and repair. Efforts to meet the demand by increasing the rate of utilization of existing generating units will increase operating costs. Construction has been halted on several large nuclear power plants that were projected to come on line in the 1980s because of high costs and public concerns for safety (Reference 29).

A projection of demand plotted against a prediction of available power shows a crossover point about 1995 (Reference 6, p. 139). Before that time, increased brownouts are projected; after 1995, serious blackouts may occur. This trend, if not changed, could seriously effect operations at some AF bases and installations, which may find themselves in competition with the private sector for the purchase of power. Some airbases with onbase generating capacity may be forced to generate more of their own power, especially during peak demand hours. Similarly, pressure may be applied through Congress and DOD to make most military installations self-supporting (with regard to power) rather than continuing to compete with the private sector.

Throughout the Air Force there is an ever increasing need for reliable, high-quality electrical power. With more and more computers and greater numbers of electronic systems on every airbase the demand for high-quality, reliable electrical power continues to expand (Reference 6, pp. 132-141). Highly reliable standby power for critical facilities is essential. Many systems are required to provide 0.99999 reliability and demand very high-quality power with very little variation in voltage, frequency, etc. The need for such power was given top priority by AF Engineering and Services leaders at the 1986 Engineering and Services Requirements Board (Reference 30). Airbase energy managers must provide high-quality, high-reliability power all the way to the consuming device, which will require the use of uninterruptible power systems (UPS) or multiple unit generation systems — both expensive options. Where waste heat can be effectively utilized, multiple unit cogeneration systems may be more cost effective.

f. Nuclear Power

A revitalization of the nuclear power industry could occur within the next 10 years. New nuclear generating plants could begin producing power within the next 20 years. The apparent onset of the "greenhouse effect," and several other adverse effects resulting from increased consumption of fossil fuels, have caused a number of environmentally conscious scientists and world leaders to reanalyze the desirability of nuclear power. Some environmental groups, formerly opposed to nuclear power, are now beginning to suggest that it may not be so bad (References 17, pp. 23-25, and 31). The world survived Three-Mile Island, Chernobyl, and other tragedies, and time seems to have diminished some of the concerns relative the safety of nuclear power (Reference 32). The recent Valdez oil spill has further shown that potential life-threatening disasters are not limited to the nuclear power industry. Nuclear power researchers have recently announced the development of a new modular, helium-cooled reactor, which is advertised to be "melt-down safe" and could lead to a resurgence of the nuclear power industry (Reference 33). Finally, the Nuclear Regulatory Commission (NRC) and the federal government have begun to realize that the complex licensing process required for nuclear power plants is so restrictive that it essentially precludes any new construction in the industry (Reference 34). The National Energy Strategy seeks to reverse this trend and to make necessary changes to ease these restrictions and encourage new investment in the nuclear power industry (References 6, pp. 181-186, 21, pp. 18-20, and 27).

C. ENERGY AND THE ENVIRONMENT

People all over the world are beginning to respond to the rapid increase in awareness, understanding, and concern for the energy/environment status of the earth. The combined term "energy/environment" is more frequently being used because in many respects the words cannot be separated. Nearly every energy-related activity carries with it some degree of environmental consequence (Figure 8). It is indeed the manner in which we have produced and consumed various forms of energy that has led to some of the environmental concerns just now being recognized (as noted below).

1. The burning of coal in industrial and power generation plants has been linked to acid rain and the degradation of forests and streams.
2. The escape of chlorofluorocarbons from refrigeration systems is considered a cause of holes in the earth's protective ozone layer.
3. The combustion of petroleum in millions of automobiles is a major cause of smog and air pollution in the cities where we live.
4. Extensive oil spills from tankers are fouling beaches and wetlands and killing coastal wildlife.

The constant burning of fossil fuels continues to dump great quantities of carbon dioxide into the atmosphere. Many scientists around the world are now convinced that this process is creating a "greenhouse" effect, that is, trapping heat in the earth's atmosphere and causing a gradual rise in temperatures over the surface of the earth resulting in very serious consequences (References 35 through 37). While not all scientists are in agreement regarding the greenhouse effect, there are a sufficient number of people concerned to begin forcing some major changes (Reference 38). To help stimulate conservation or the use of alternative sources of energy, officials in Britain and Europe have proposed imposing a "carbon tax" on all consumption of fossil fuels. Two US congressmen have proposed a similar tax for the United States (Reference 39); Senator Albert Gore (D-Tennessee) recently stated his support for a carbon tax at a Department of Energy/American Solar Energy Society roundtable on renewable energy (Reference 40). This additional cost would be passed on to consumers and serve to encourage them to seek noncarbon sources to meet their energy needs. While a carbon tax may not be imposed for some time, it is clear that pressures to reduce the consumption of fossil fuels are mounting. Such pressures could

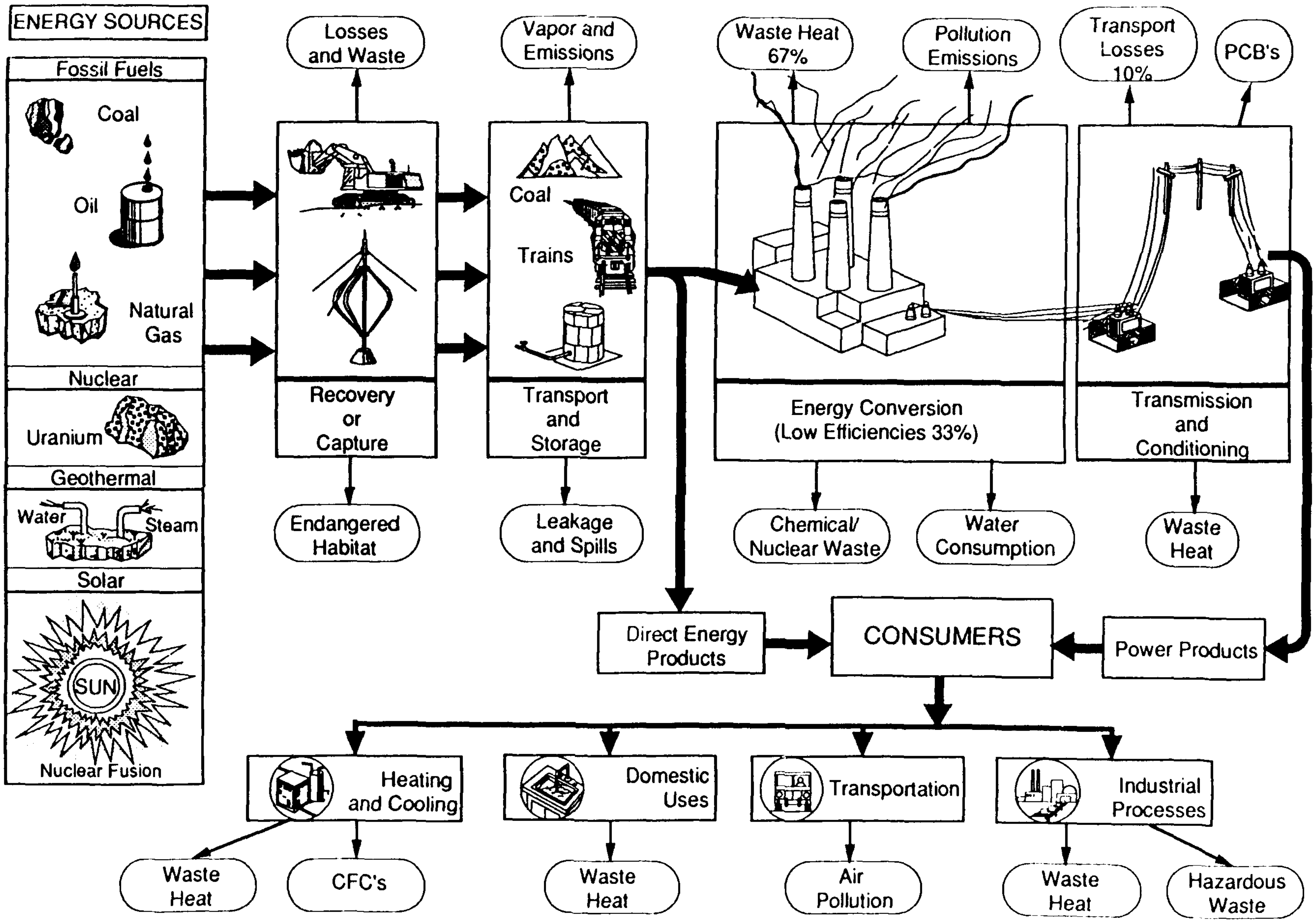


Figure 8. Links Between Energy and the Environment.

place supplies of energy for military bases in serious jeopardy. It is not unrealistic to envision a federally mandated reduction in energy produced from fossil fuels at all military bases sometime in the future, similar to the recent Executive Order (17 Apr 1991) mandating a switch to alternative fuels for federal vehicle fleets.

Major changes in the types of fuels used in base vehicles or fleets may also occur. President Bush has proposed that a million "ultra-clean" vehicles be in use by the end of the decade (Reference 41). This goal would be achieved through the use of methanol, ethanol, compressed natural gas, or other modified fuels. Although Congress has not fully supported this proposal, the recent Executive Order mandates federal motor vehicle fleets be converted to operate on alternative fuels as soon as is practical, a requirement likely to apply to fleet vehicles on military bases.

Increasing concerns about the depletion of the ozone layer surrounding the earth (Reference 42) led to the 1986 Montreal Protocol, which mandated a freeze in the production of chlorofluorocarbons by the year 2000. This will affect nearly all of the refrigerated air-conditioning systems at airbases throughout the world. Hydrochlorofluorocarbons (HCFCs) are the leading candidates for replacing CFCs in refrigeration systems; however, they are expected to be less efficient for cooling than CFCs and thus substantially more energy will be required to provide equivalent cooling (Reference 43). Unfortunately, most large cooling systems at military bases are powered by electricity, which is the most expensive form of energy (7 to 8 times more costly than natural gas). Thus, as CFC refrigeration systems on military bases are replaced with HCFC systems, energy managers can expect significant increases in costs, unless a change is made from electrical power as well.

SECTION IV
AIR FORCE ENERGY CONSUMPTION

A baseline of facilities/utilities energy consumption for USAF airbases has been developed using existing consumption data, reports relating to this topic, visits to MAJCOMS and individual bases, and questionnaires sent to each airbase and MAJCOM.

A. DEFENSE ENERGY INFORMATION SYSTEM DATA

Most of the information used to establish a baseline of airbase energy consumption has been obtained from the Defense Energy Information System (DEIS II) database. Mandated by AFEPPM 86-6, all USAF airbases have been required to report, on a monthly basis, comprehensive data regarding the amount and type of all of the facilities/utilities energy consumed, heating and cooling weather data, airbase facilities square footage data, and costs for energy consumed. Over the past five years (FY 1985 through FY 1989) these data have been collected, consolidated, and retained in a database at the Air Force Civil Engineering Support Agency (AFCESA) at Tyndall AFB, FL. A listing of USAF MAJCOMS and airbases included in the DEIS II database is provided in Appendix A. A printout of DEIS data for a typical base is shown in Table 2. Data for 1990 have only recently become available and were not included in this study.

1. Airbase Level Energy Plots

Data from the DEIS database at AFCESA were transferred to the mainframe computer at the New Mexico Engineering Research Institute (NMERI), and software was developed to download these data to desktop computers for processing. The computer software steps used in the process are listed in Appendix B. Some amount of work was required to align all the data with consistent energy conversion units and reporting formats. Commercially available software was then used to plot the data into useful graphs and charts. (The common unit for reporting DEIS data is million British thermal units [MBtu]). Data from nearly all AF airbases have been plotted into standard charts depicting the energy posture of each base over the past five years. Figures 9 through 14 are a typical set of these charts (Offutt AFB was arbitrarily selected). Notebooks for each MAJCOM containing the energy plots for each airbase in the command plus the MAJCOM level plots were compiled and used during visits to each MAJCOM and airbase. A complete set of these plots for all the USAF bases examined in this study is provided in Volume II of this report.

TABLE 2. PRINTOUT OF DEIS DATA FOR TYPICAL USAF AIRBASE.

DATE PREPARED: FEBRUARY 22, 1930 FY 89 OCT THRU SEP BASE CONSUMPTION REPORT KIRTLAND AFB MAC

SQUARE FOOTAGE (000)

TOTAL =	6117	IND	GEN OPS =	0	IND	NEW =	0	IND	EXISTING =	6117	IND
	3051	MFH		0	MFH		0	MFH		3081	MFH
	9198			0	TOT		0	TOT		9198	TOT

DEGREE DAY DATA

COOLING DEGREE DAYS = 937 HEATING DEGREE DAYS = 3742

CONSUMPTION IN MBTU

PRODUCT	USE	TOTAL	GEN OPS	NEW	RENEWABLE	COLD IRON	EXISTING	COST	COST/MBTU
ELC	IND	205928	0	0	0	0	205928	3794764	18.42
	MFH	58730	0	0	0	0	58730	1079927	18.38
	TOT	264658	0	0	0	0	264658	4874691	18.42
FSD	IND	14881	0	0	0	0	14881	75280	5.05
	MFH	0	0	0	0	0	0	0	0.00
	TOT	14881	0	0	0	0	14881	75280	5.05
NAG	IND	449475	0	0	0	0	449475	992553	2.20
	MFH	225941	0	0	0	0	225941	588380	2.60
	TOT	675416	0	0	0	0	675416	1580933	2.34
PPG	IND	9536	0	0	0	0	9536	61170	6.41
	MFH	0	0	0	0	0	0	0	0
	TOT	9536	0	0	0	0	9536	61170	6.41
SHW	IND	138014	0	0	0	0	138014	735097	5.32
	MFH	0	0	0	0	0	0	0	0.00
	TOT	138014	0	0	0	0	138014	735097	5.33
TOT	IND	817834	0	0	0	0	817834	5658864	6.91
	MFH	284671	0	0	0	0	284671	1668307	5.86
	TOT	1102505	0	0	0	0	1102505	7327171	6.65
MBTU/SF	IND	0.1337	0.000	0.000			0.1337		
	MFH	0.0924	0.000	0.000			0.0924		
	TOT	0.1199	0.000	0.000			0.1199		

Note: ELC (electricity); FSD (diesel fuel); NAG (natural gas); PPG (propane gas); SHW (steam/hot water).

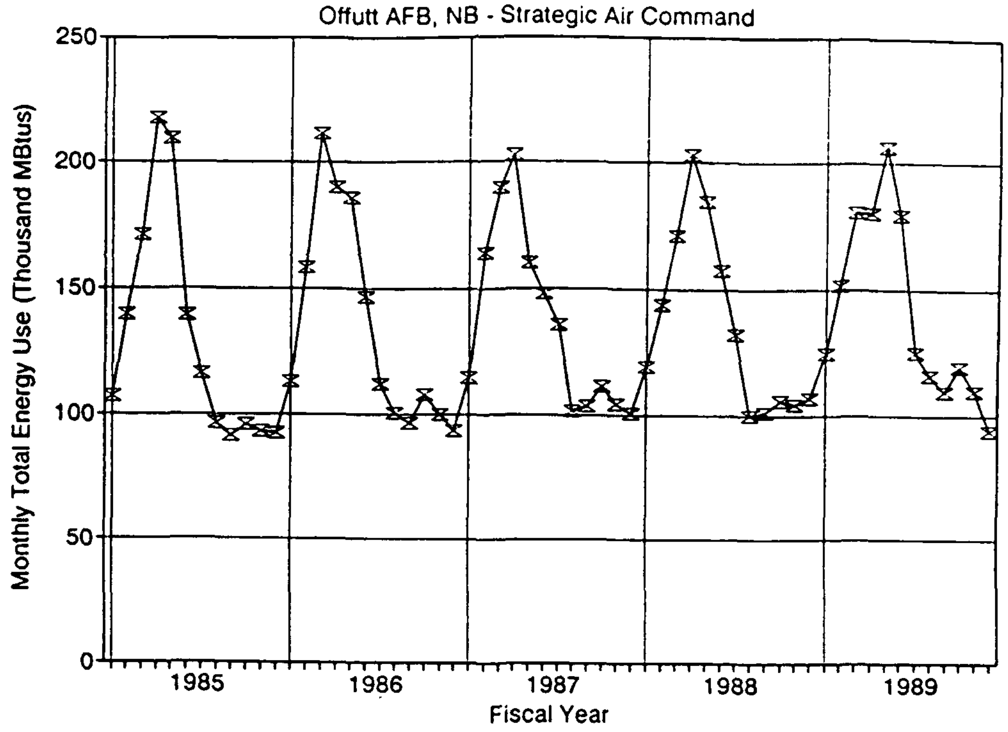


Figure 9. Offutt AFB: Monthly Total Energy Consumption.

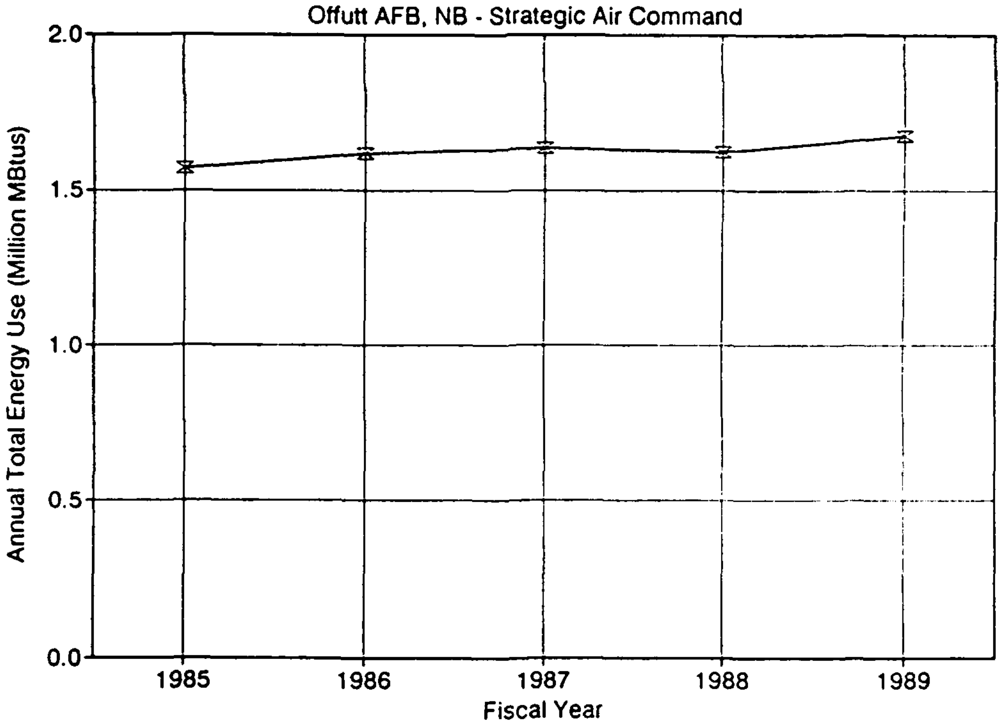


Figure 10. Offutt AFB: Annual Total Energy Consumption.

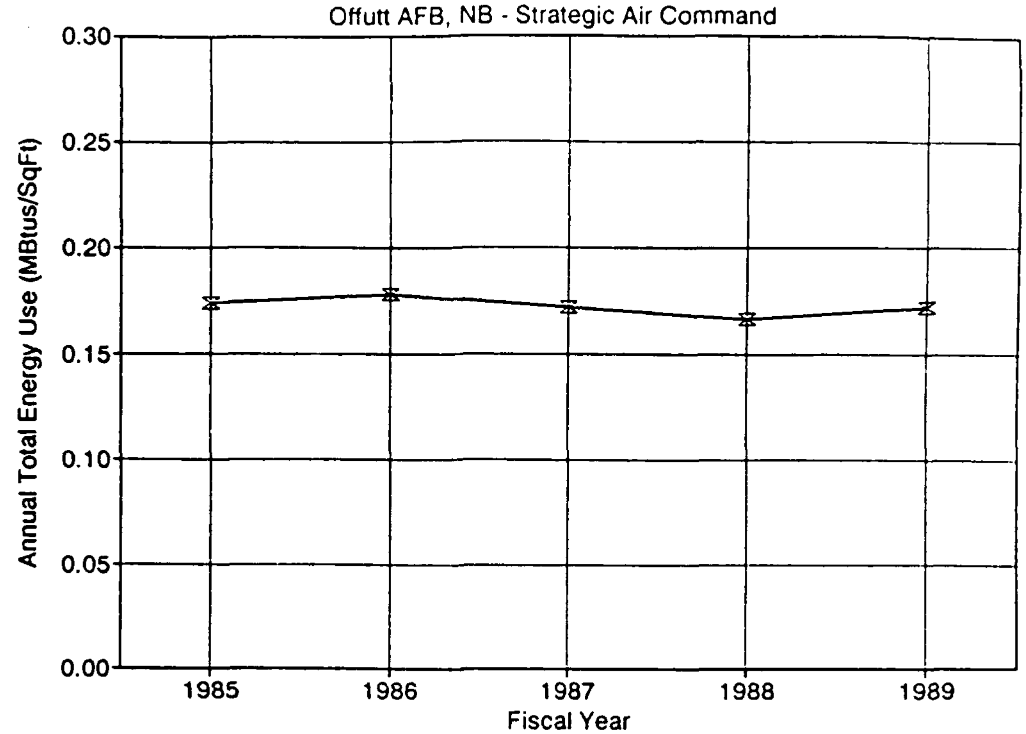


Figure 11. Offutt AFB: Annual Total Energy Consumption, Normalized to Floor Area.

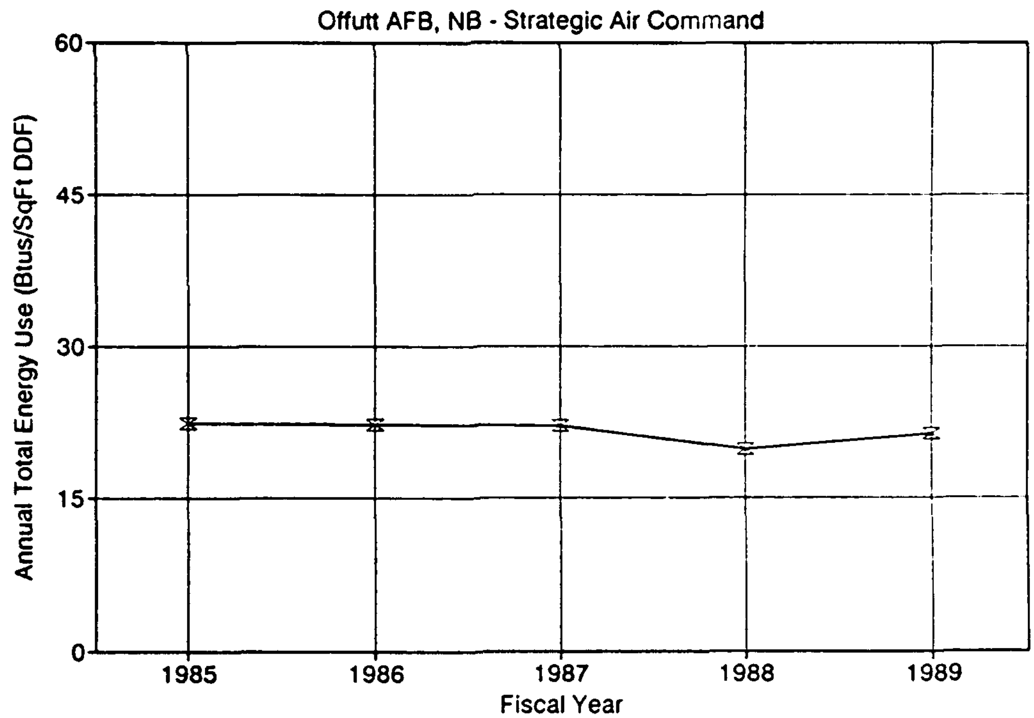


Figure 12. Offutt AFB: Annual Total Energy Consumption, Normalized to Both Floor Area and Degree Day Factor.

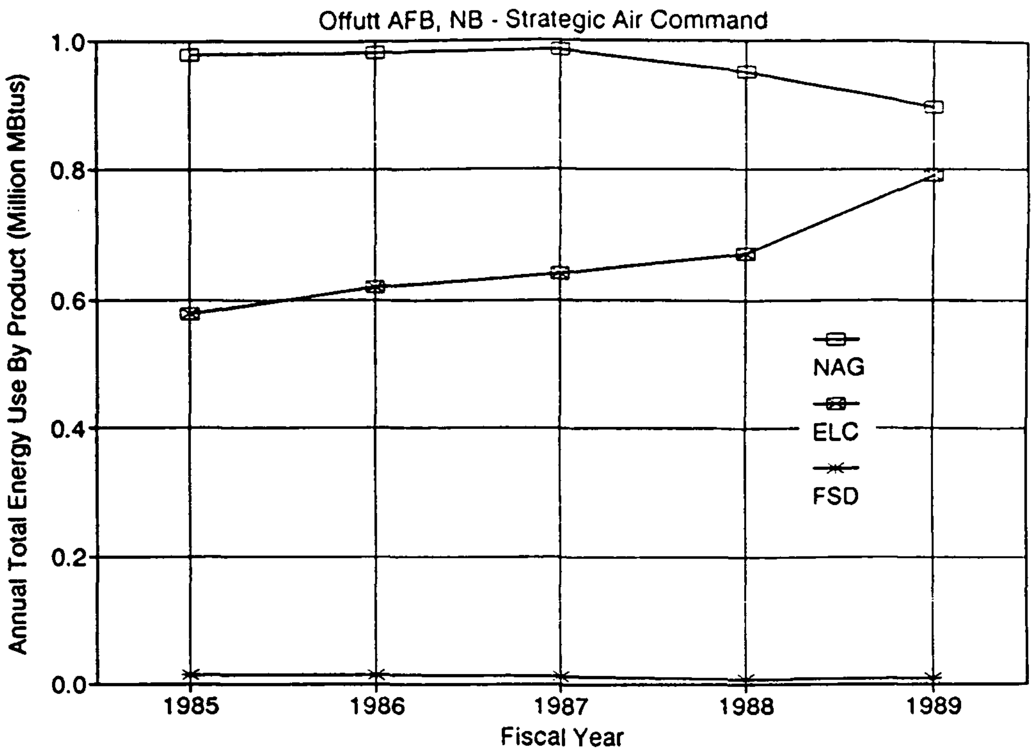


Figure 13. Offutt AFB: Annual Consumption of Each Type of Energy Product.

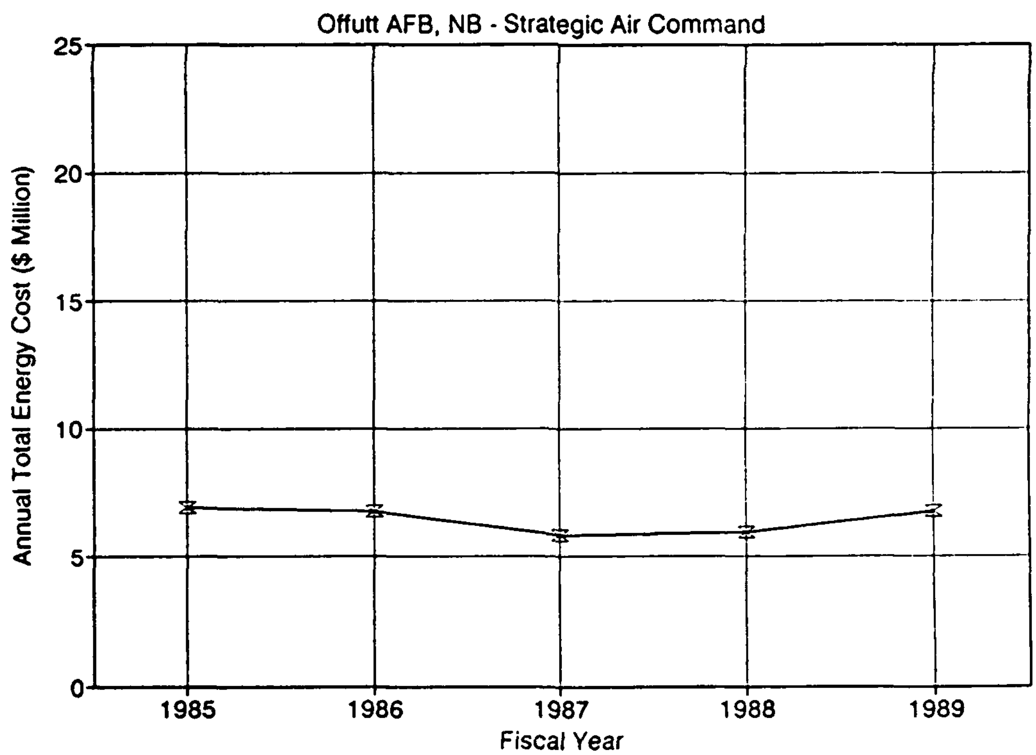


Figure 14. Offutt AFB: Annual Total Energy Costs.

Figure 9 shows the monthly consumption of all facility/utility energies for Offutt AFB from FY 1985 through 1989. Figure 10 is a summary of all the monthly data for each fiscal year and traces the yearly consumption for Offutt over that period. To calculate the difference in size for various airbases, a normalizing parameter is created by dividing the total energy consumed by the number of square feet of facility floor area on the base ($MBtu/ft^2$). (Facilities floor area is defined as all enclosed and usable floor area on the base.) This parameter, normalized to facilities floor area, is used in the DEIS as the measure of energy effectiveness for military bases. The normalized energy consumption for the airbase over the 5-year period is shown in Figure 11.

Airbases in diverse locations can have vastly different weather conditions, which greatly affect airbase energy consumption. To account for these variations, a combined weather and floor area normalizing factor was developed. Both heating and cooling degree days[1] for each airbase are recorded in the DEIS database for each fiscal year. Since it requires approximately twice as much energy for a unit of cooling as for a unit of heating, a degree-day factor (DDF) for each airbase was created by multiplying the cooling degree days by 2 and adding that product to the heating degree days. By dividing the total energy consumed by both the total floor area and the degree-day factor, a more complete normalization of airbase energy consumption is achieved ($MBtu/ft^2$-DDF). The energy consumption for Offutt AFB, normalized to both floor area and weather, for this period, is shown in Figure 12. This energy consumption, normalized to both weather and floor area, is probably the best measure of airbase energy efficiency that can be reasonably obtained from the DEIS data.

The amount of each type of energy product (electricity, natural gas, coal, fuel oil, etc.) consumed on each airbase is also recorded in the DEIS database. The products consumed by Offutt AFB over this period are shown in Figure 13. These plots are extremely valuable for understanding the trends in consumption of the various types of energy by each airbase.

Finally, both the price and total cost for each type of energy product consumed are recorded in the DEIS database. Plots of the total annual energy costs were constructed for each airbase. These plots are essential for developing baseline energy cost trends. An example is seen in Figure 14.

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[1] Degree day: A measure of how much the outdoor temperature varies from 18 °C (65 °F) — used to indicate weather-related energy consumption. Temperatures greater than 18 °C (65 °F) contribute to cooling degree days, below 18 °C (65 °F) to heating degree days.

2. MAJCOM Level Energy Plots

After constructing individual airbase level energy plots, it was possible to construct consolidated MAJCOM level plots where all of the airbases assigned to a MAJCOM are recorded. This approach allows a comparison of the energy effectiveness of the several bases within each MAJCOM and can be used to identify important trends for that command. The first MAJCOM level plot is constructed by overplotting the total annual energy consumption data for each airbase (Figure 15). The Strategic Air Command (SAC) has been selected arbitrarily as an example for these MAJCOM plots. As would be expected, the energy consumption by individual bases varies widely because of airbase size, location (weather), assigned mission, and assigned AF systems. The second MAJCOM plot shows the energy consumption normalized to floor space for all of the airbases in the command (Figure 16). This is the parameter used with the DEIS to determine how well individual airbases are meeting their energy reduction goals. As would be expected, some reduction in the scatter between individual airbases can be observed when compared with Figure 15, but substantial scatter still exists because of the varying locations and associated weather. Figure 17, the overplot of energy consumption normalized to both floor space and weather, is probably the most revealing. This plot most accurately compares the true energy effectiveness of all the airbases in the command. Further consolidation of all the airbases into a tighter band can clearly be observed. Differences shown here more truly represent actual disparities in energy effectiveness among the airbases; however, the individual airbase missions and assigned weapon systems may still contribute to these variances. Overplotting of the cost data from all the airbases shows the spread and trends in energy costs across the entire command (Figure 18).

The individual values from each airbase are used to generate summary plots for the MAJCOM. In Figure 19 the total consumption by the command of all forms of facilities/utilities energy over 5 years is plotted. The total MAJCOM energy normalized to floor area is plotted in Figure 20. Total amounts of each type of energy product are shown in Figure 21 and total MAJCOM energy costs in Figure 22. (A complete set of MAJCOM plots is included in Volume II of this report.)

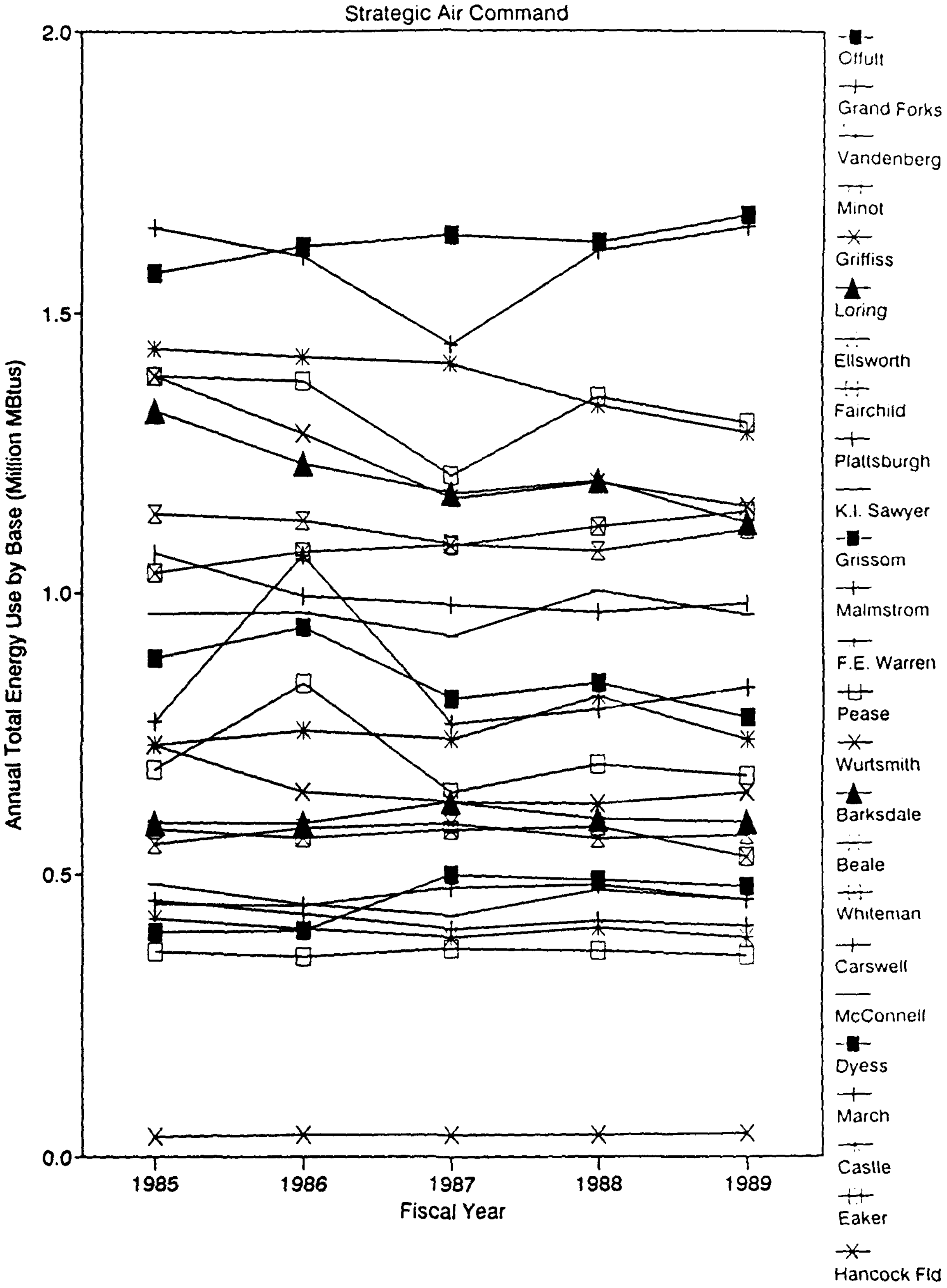


Figure 15. A Comparison of the Total Energy Consumed by Each Airbase in SAC.

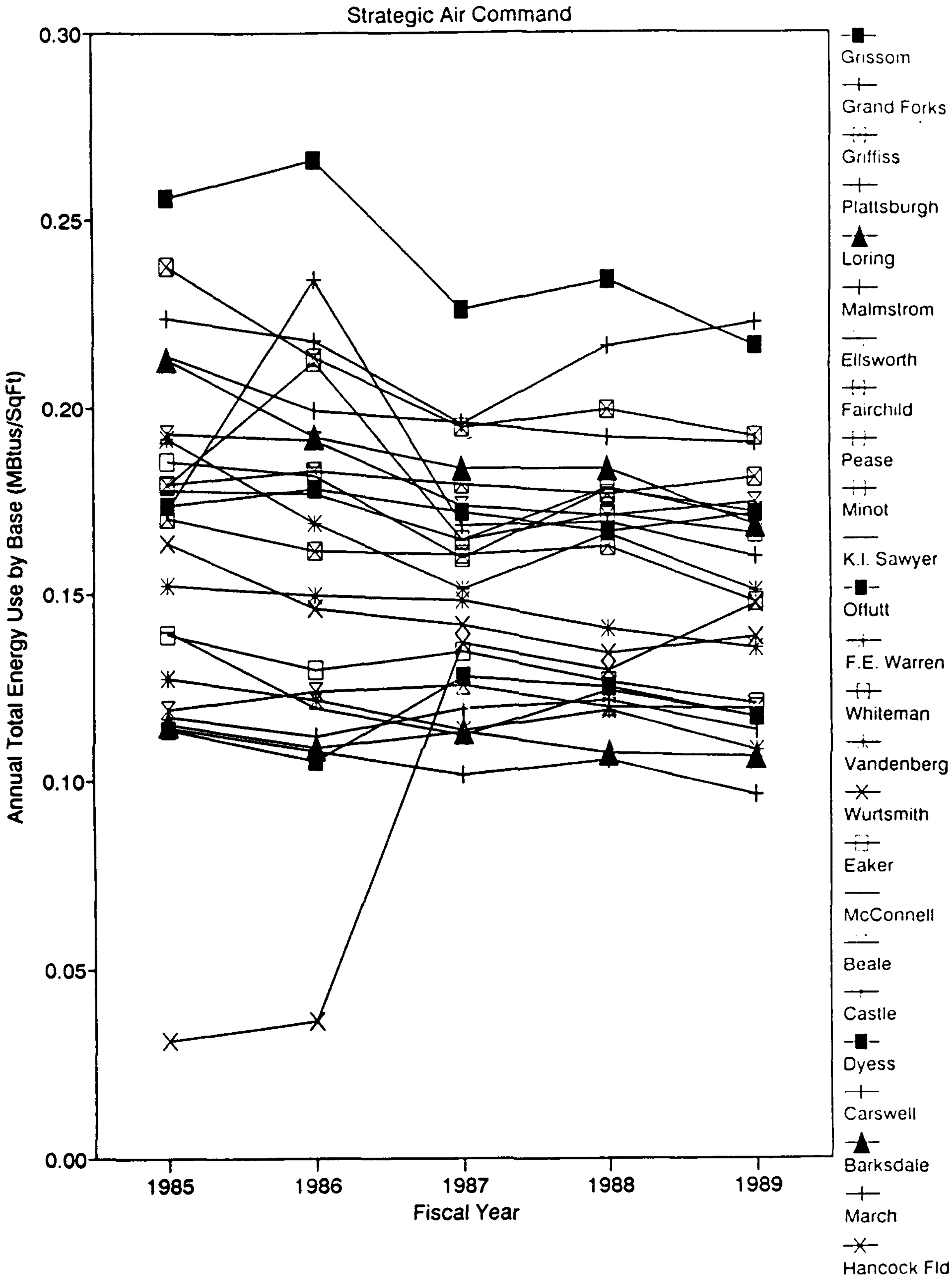


Figure 16. A Comparison of the Total Energy Consumed, Normalized to Floor Space, for Each Airbase in SAC.

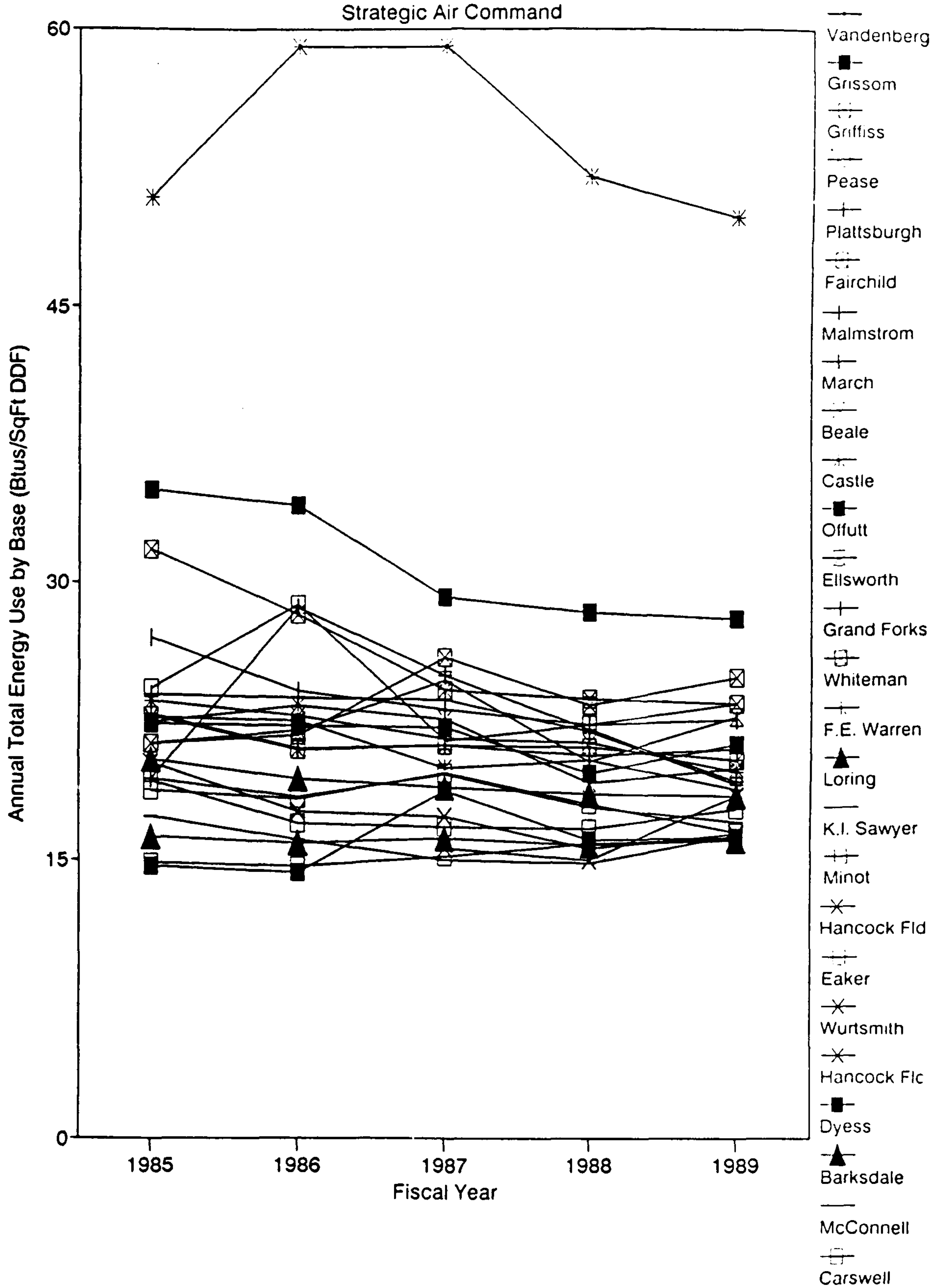


Figure 17. A Comparison of the Total Energy Consumed, Normalized to Both Floor Space and Degree Day Factor, for Each Airbase in SAC.

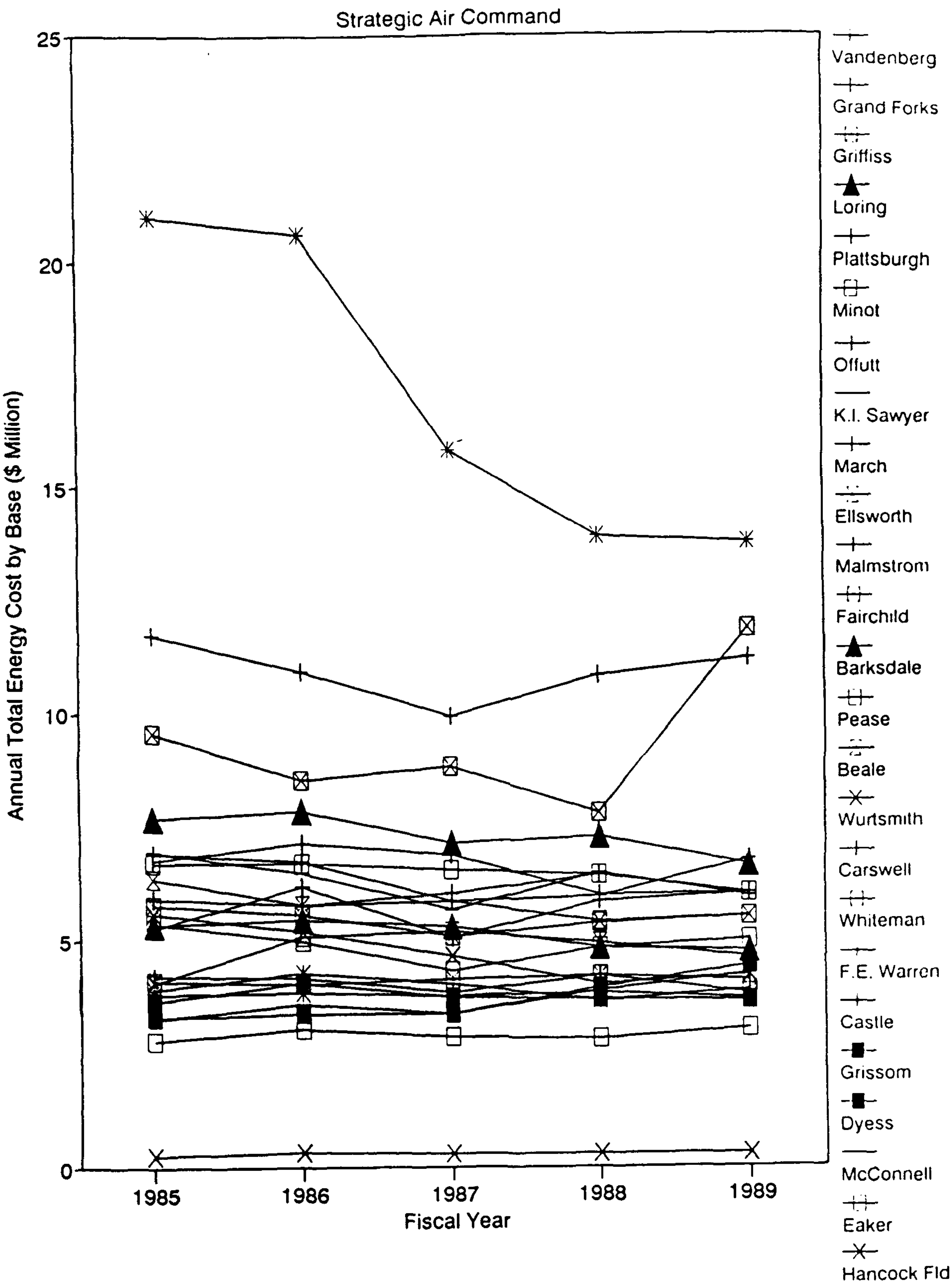


Figure 18. A Comparison of Total Energy Costs for Each Airbase in SAC.

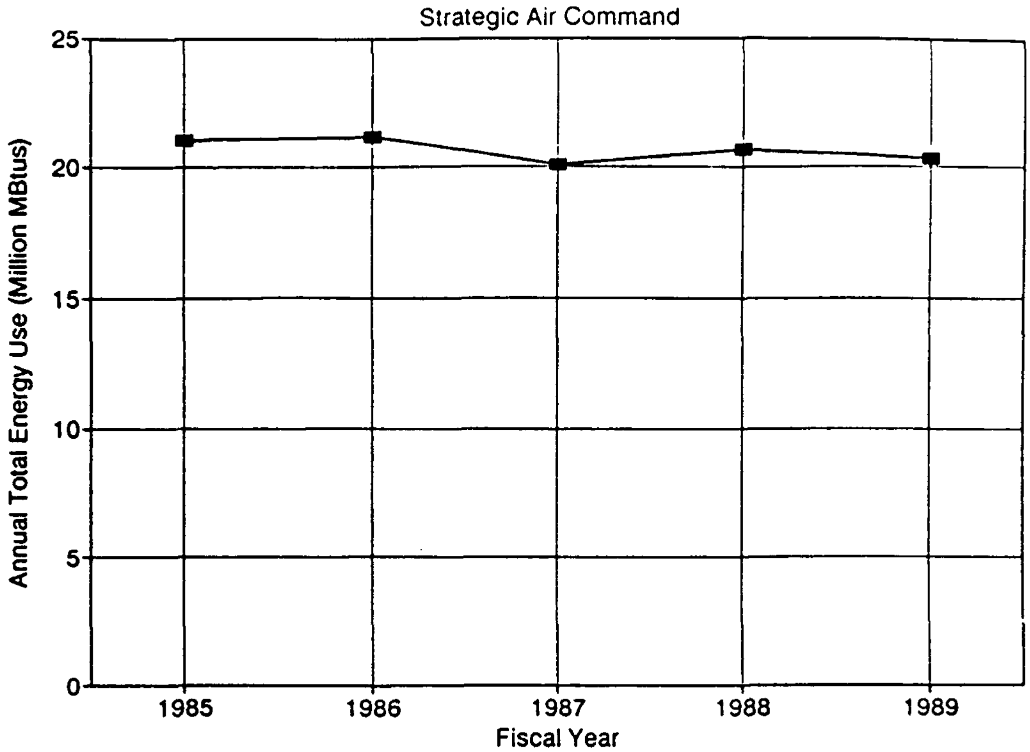


Figure 19. Annual Total Energy Consumption by SAC.

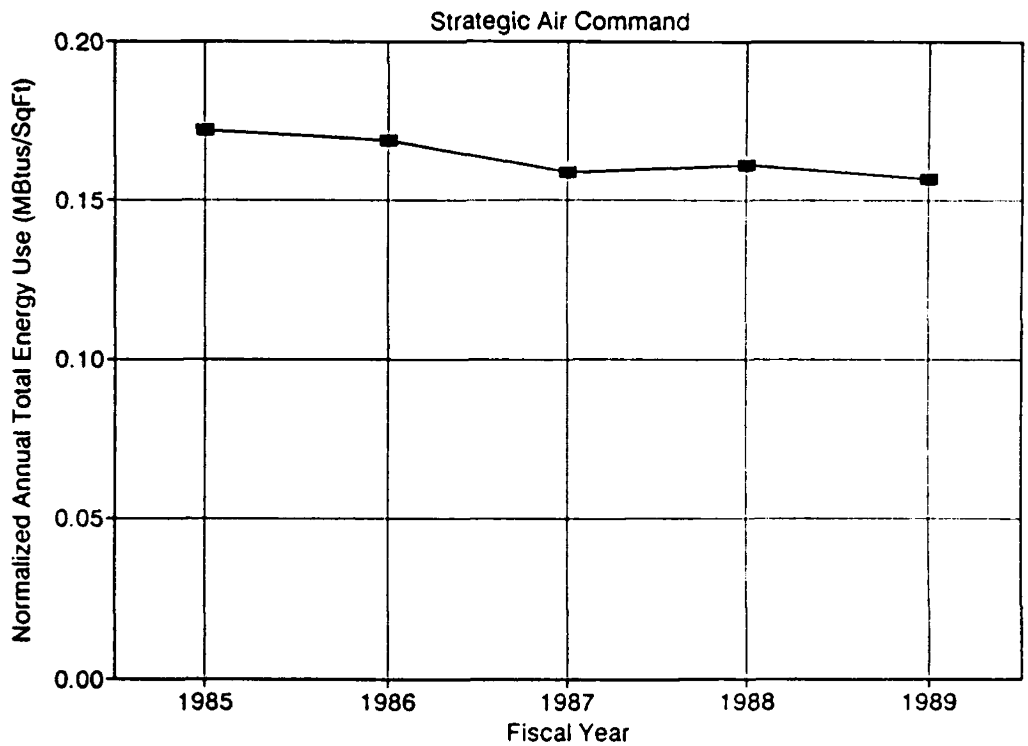


Figure 20. Annual Total Energy Consumption by SAC, Normalized to Floor Area.

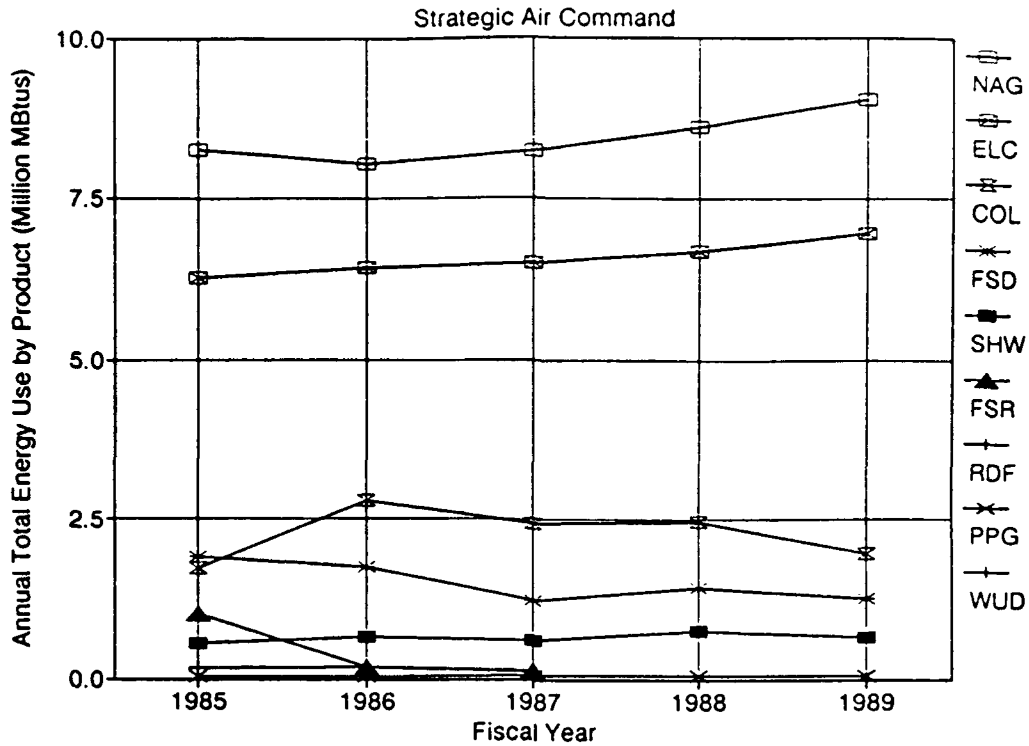


Figure 21. Annual Total Consumption of Each Type of Energy Product by SAC.

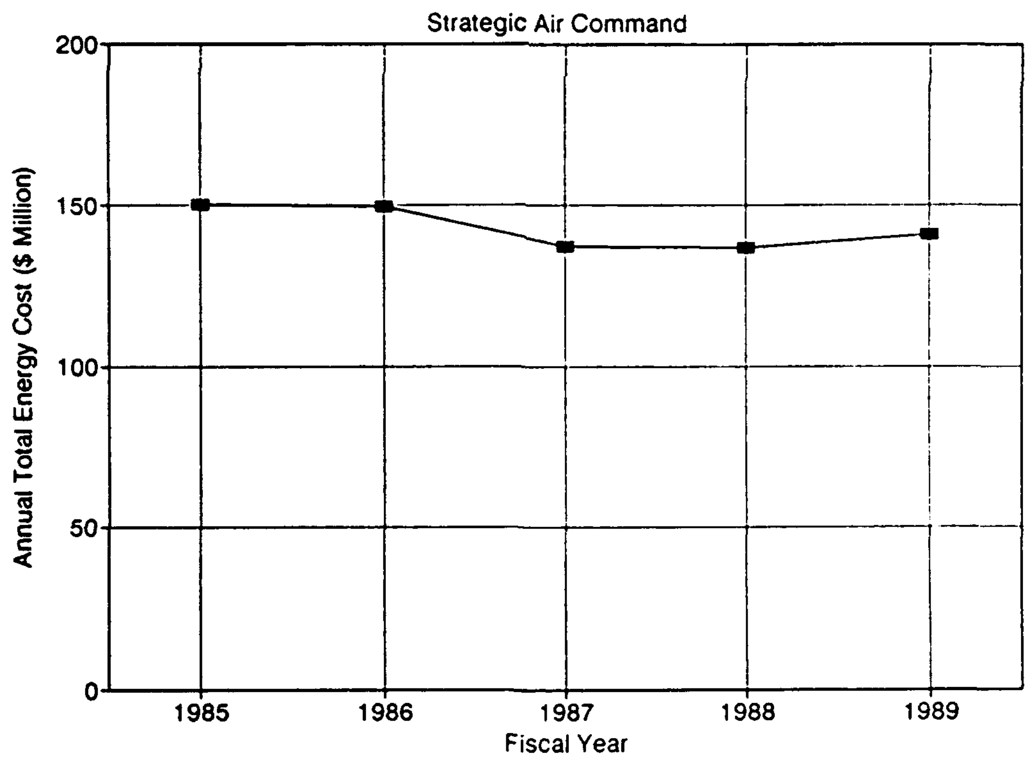


Figure 22. Annual Total Energy Costs for SAC.

3. Correlations of Energy Plots and Weapon Systems

An essential element in the establishment of a baseline of USAF energy consumption is understanding how various weapon systems in each MAJCOM relate to airbase energy consumption. To gain insight into such possible relationships, each airbase in the MAJCOM with an assigned weapon system (F-15, B-1, B-52, F-16, etc.) was overplotted with other airbases having that same assigned weapon system. The parameter plotted is the total airbase energy consumption normalized to both base size (floor area) and weather (DDF). For example, airbases with both B-52s and tankers (Figure 23), show good convergence with a relatively narrow scatter band, resulting in an average value near 20 MBtus/ft^2-DDF in 1989.

To understand how the several weapon systems in each command influence the airbase energy consumption in that command, a least-squares fit was placed through all of the data for each weapon system (for example, Figure 23) for each command. An example of such a least-squares fit to the data from Figure 23 is shown in Figure 24. The weapon systems assigned to individual SAC airbases are shown in Figure 25. The least-squares fits to the normalized energy consumption data for SAC airbases with each type of strategic weapon system are also shown in Figure 25. Similar listings of weapon systems assigned to each MAJCOM airbase are given in Figures 26 through 30, which also provide the least-squares fits to the normalized energy consumption data from airbases for the different types of weapon systems assigned to the remaining MAJCOMs.

B. VISITS TO MAJCOMS AND AIRBASES

To assure the accuracy of collected data and obtain additional information, members of the AFCESA/RACO project staff and the NMERI research team visited all of the MAJCOMS and several airbase-level civil engineering organizations (Table 3). Meetings with MAJCOM energy managers served to examine and validate the DEIS data recorded for that MAJCOM, to discuss airbase energy problems across the command, to learn of new weapon systems that might be assigned to the command and associated airbase energy problems that might accompany the new systems, to gather information regarding upcoming modification or additions to airbase energy systems in the command, and to learn what energy-related R&D efforts the MAJCOM would recommend. At many of the MAJCOMs, the Deputy Chief of Staff for Engineering & Services (the command civil engineer) was briefed on the project and participated directly in discussions regarding airbase energy problems in that MAJCOM.

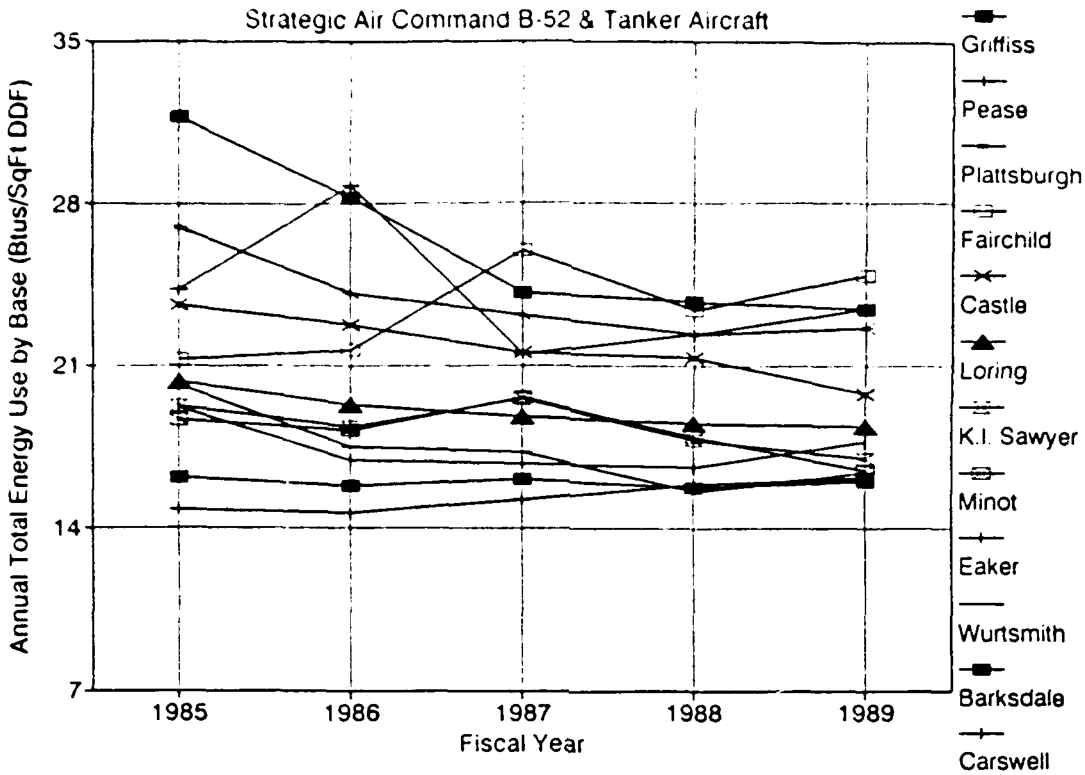


Figure 23. A Comparison of the Annual Total Energy Consumed, Normalized to Both Floor Area and Degree Day Factor, for Each SAC Airbase to Which B-52 and Tanker Aircraft are Assigned.

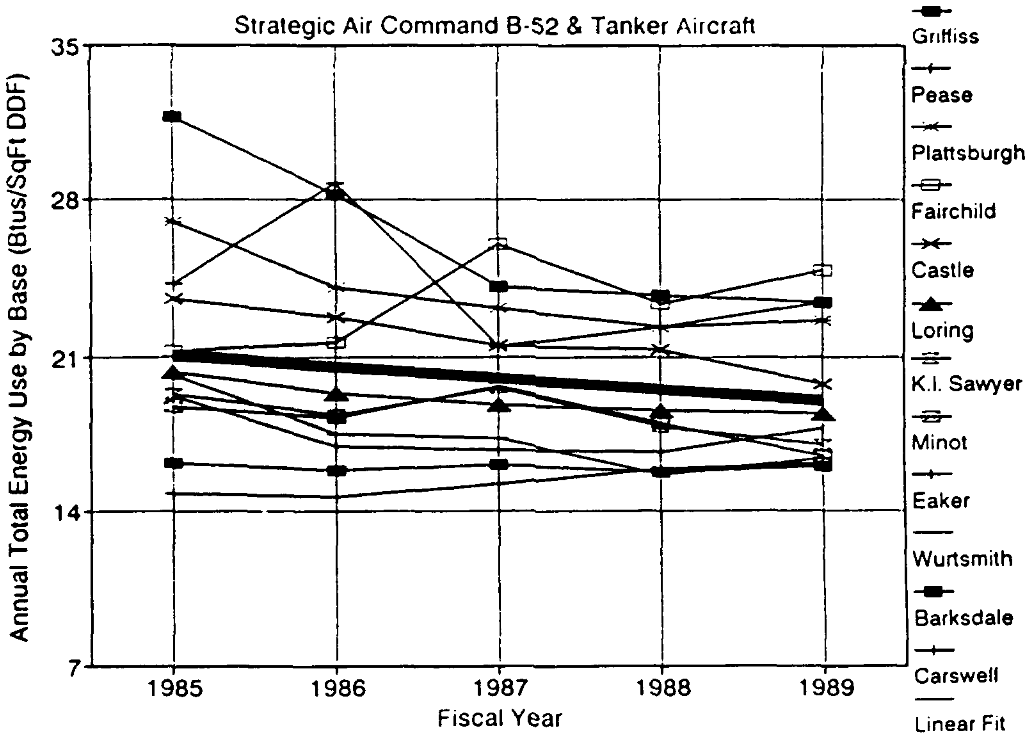
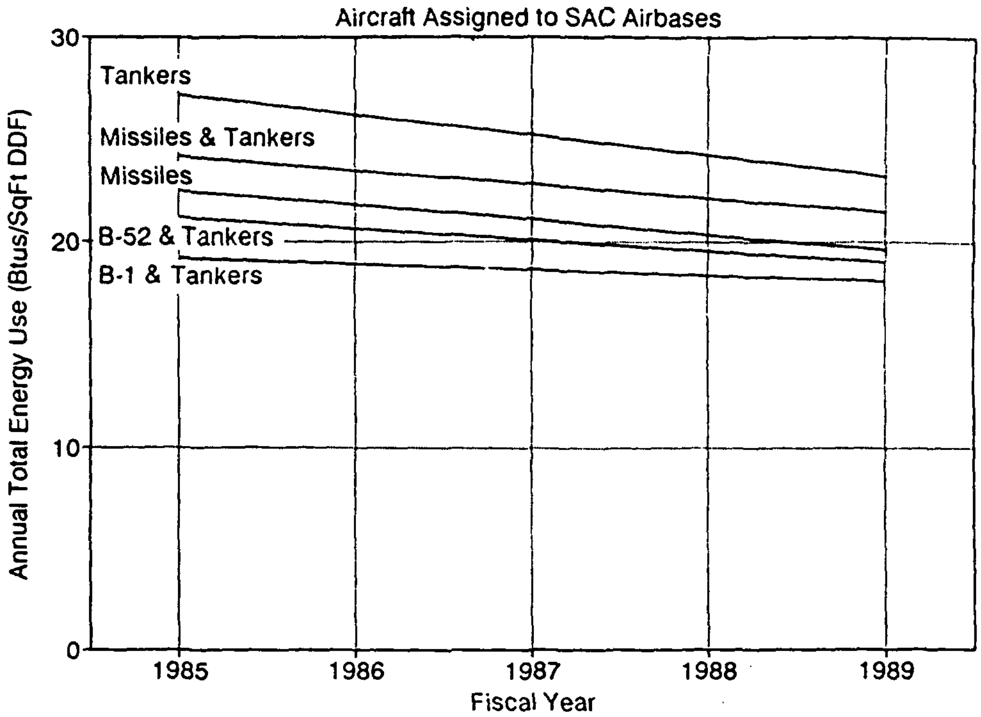
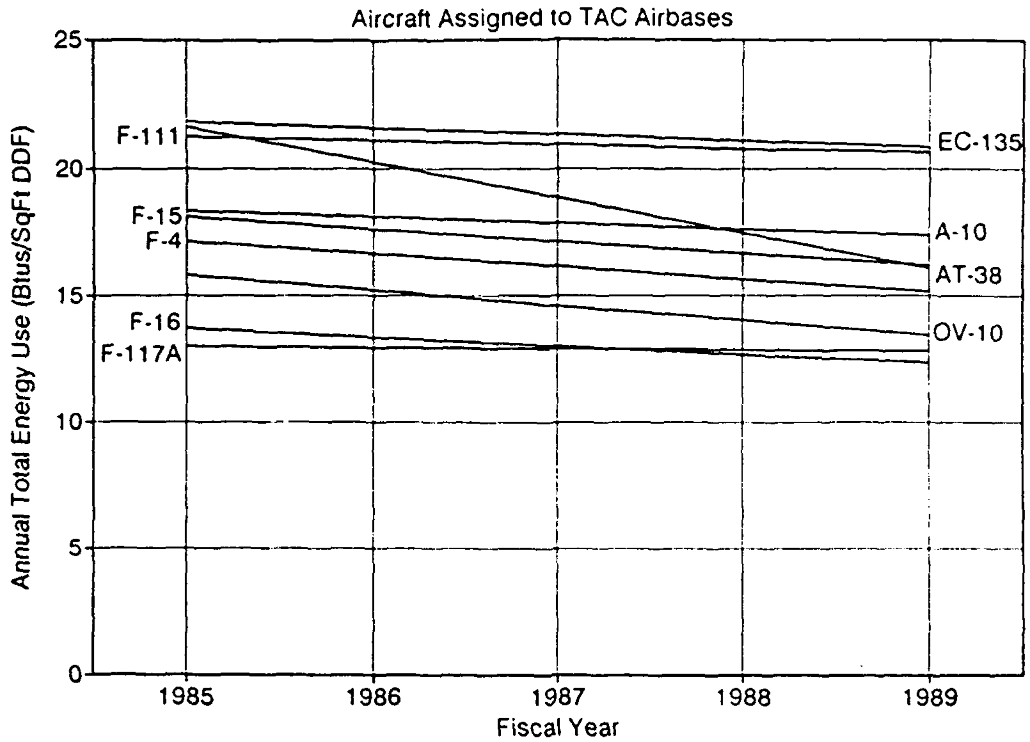


Figure 24. Least-Squares Fit to Normalized Energy Consumption for SAC Airbases with Both B-52 and Tanker Aircraft (from Figure 23).



B-52 & Tanker	B-1 & Tanker	Missiles & Tankers	Tankers Only	Missiles Only
Anderson	Dyess	Malmstrom	Beale	F.E. Warren
Barksdale	Ellsworth		Grissom	Whiteman
Baker	McConnell		March	
Carswell	Grand Forks			
Castle				
Fairchild				
Griffiss				
K.I. Sawyer				
Loring				
Minot				
Pease				
Plattsburgh				
Wurtsmith				

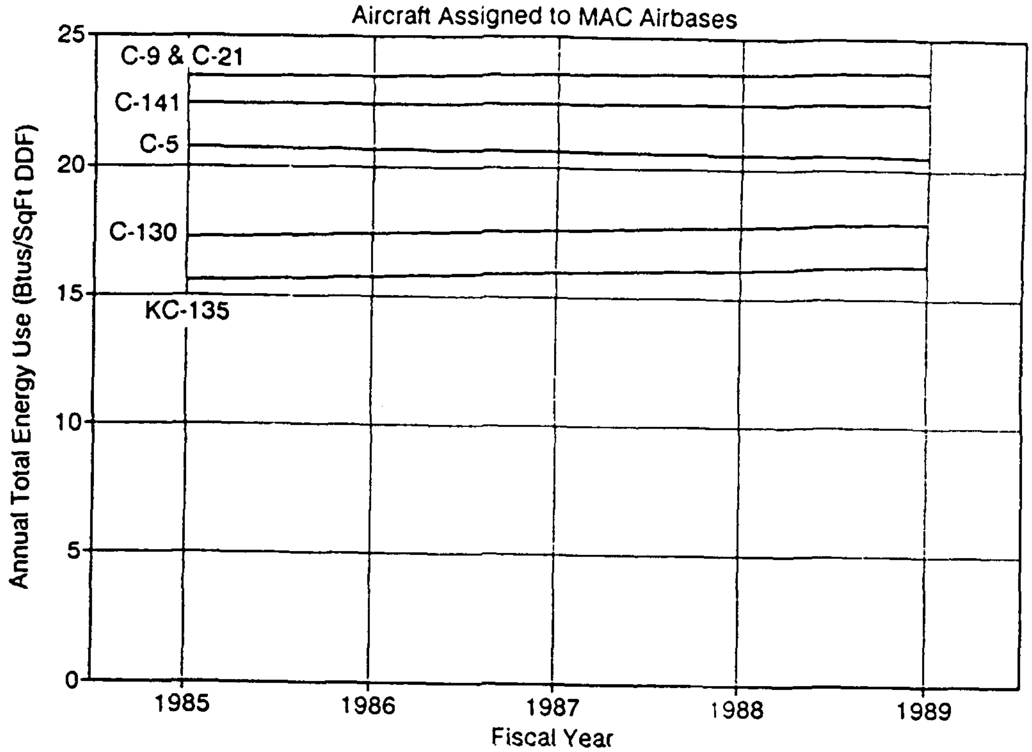
Figure 25. Least-Squares Fit to Normalized Energy Consumption for SAC Airbases with Strategic Weapon Systems.



F-15	F-16	F-4	A-10	F-11
Langley	Homestead	S. Johnson	England	Cannon
S. Johnson	Moody	George	Myrtle Beach	Mtn. Home
Holloman	Shaw	Bergstrom	Mtn. Home	
Tyndall	McDill	Nellis		
Luke	Luke			
Nellis	Nellis			

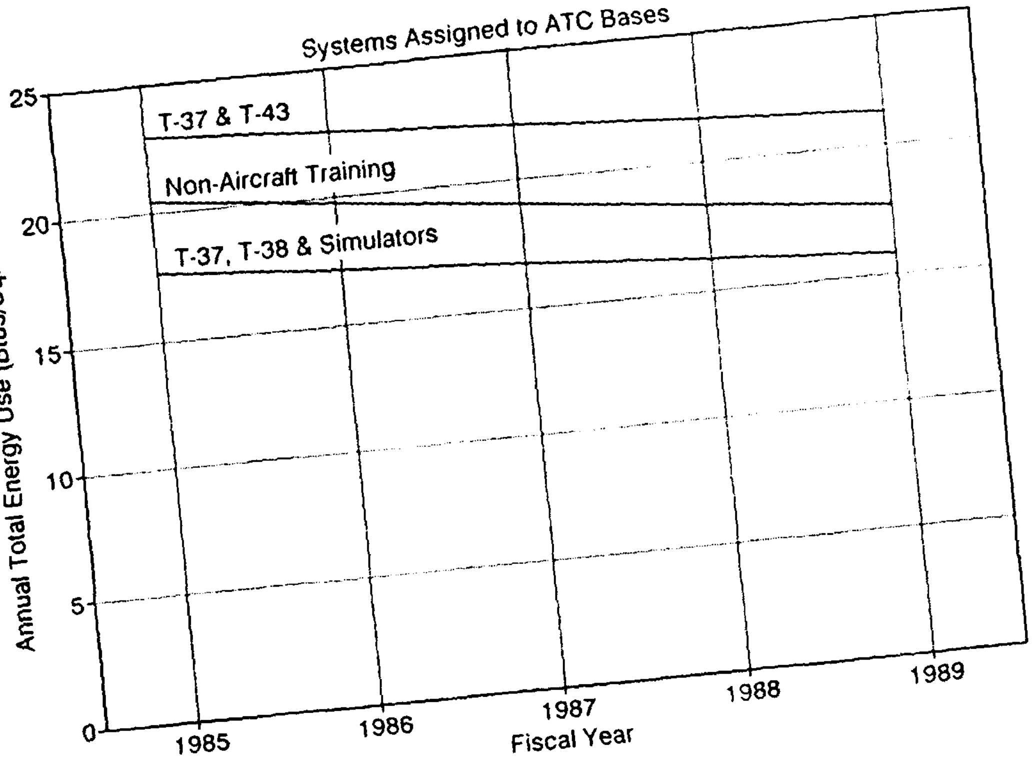
F-117A	EC-135	OV-10	AT-38
Nellis	Langley	Shaw	Holloman
		Davis-Monthan	

Figure 26. Normalized Energy Consumption for CONUS Tactical Aircraft Airbases.



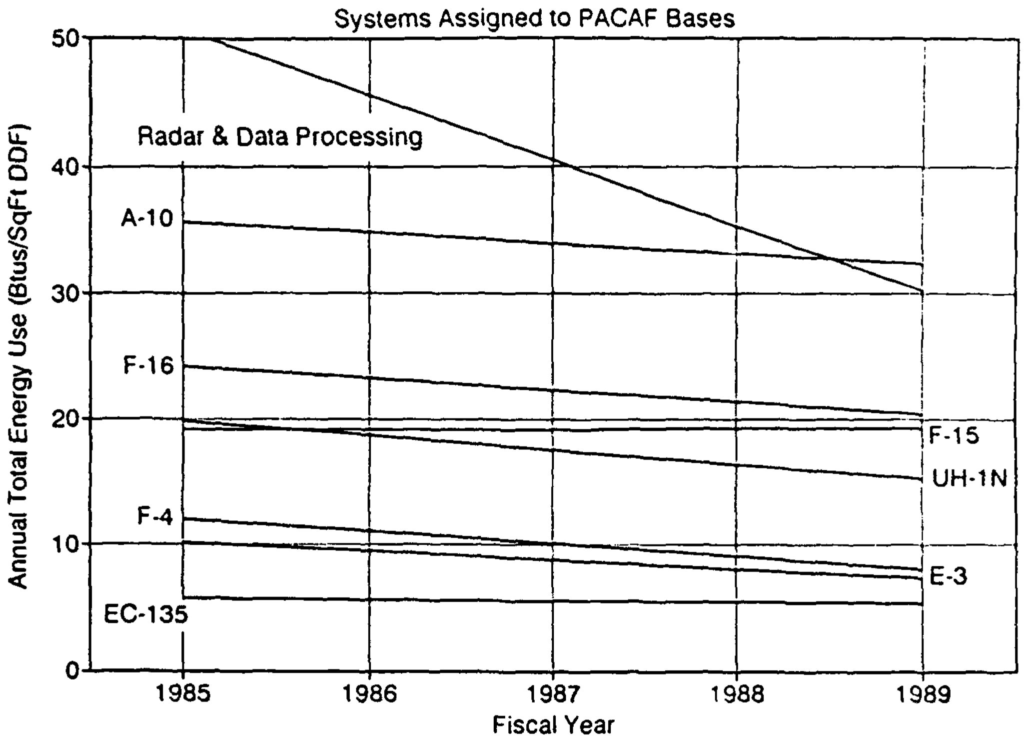
<u>C-5</u>	<u>C-141</u>	<u>C-130</u>	<u>C-9 & C-21</u>	<u>KC-135</u>
Altus	Altus	Hurlburt	Scott	Altus
Dover	Andrews	Kirtland		
Travis	Charleston	Little Rock		
	McChord	Pope		
	McGuire	Rhein Main		
	Norton			
	Travis			

Figure 27. Normalized Energy Consumption for Transport Aircraft Airbases.



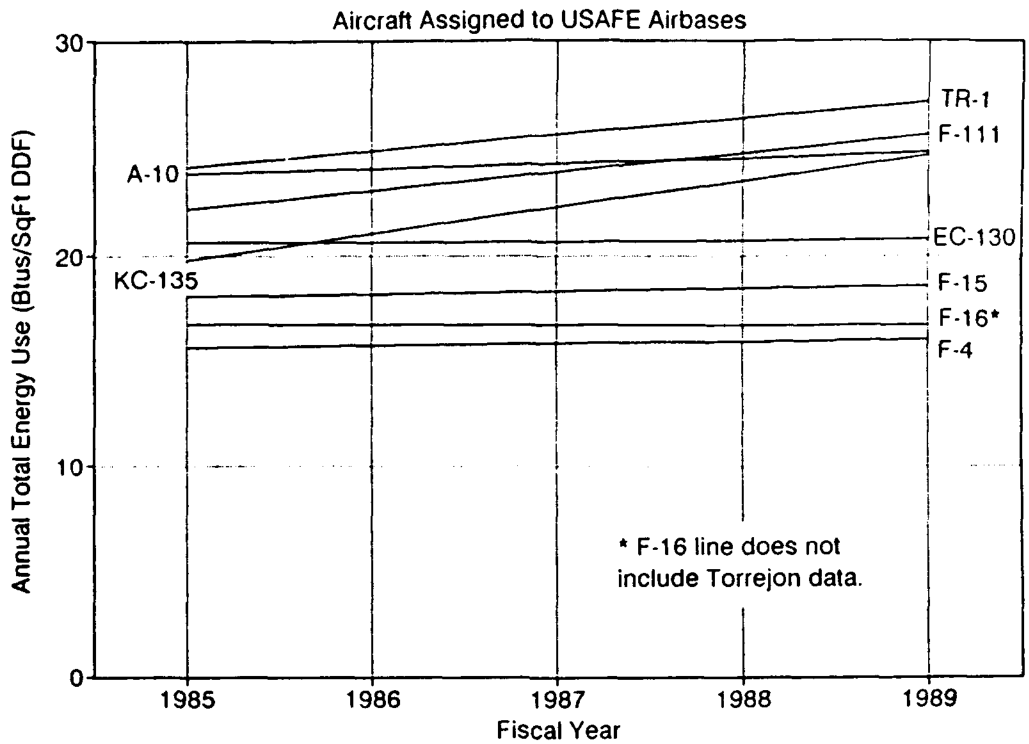
T-37 & T-43	T-37 & T-38	Non-Aircraft Training	Aircraft Simulators
Mather	Columbus	Keesler	Columbus
	Laughlin	Lowry	Laughlin
	Randolph	Chanute	Mather
	Reese	Goodfellow	Randolph
	Sheppard	Lackland	Reese
	Vance	Sheppard	Sheppard
	Williams		Vance
			Williams

Figure 28. Normalized Energy Consumption for Training Aircraft.



Radar & Data Processing Systems	EC-135	F-15	F-16	A-10
Shemya	Hickam	Kadena	Misawa	Osan
Cape Lisburne		Elmendorf	Osan	Eilson
Cape Newenham			Kunsan	
Cape Romanzof				
Cold Bay				
Fort Yukon		E-3	F-4	UH-IN
Indian Mountain		Kadena	Clark	Yokota
Kotkebue				Clark
Murphy Dome				
Sparrevohn				
Tatalina				
Tin City				

Figure 29. Normalized Energy Consumption for PACAF Airbases.



<u>EC-130</u>	<u>A-10</u>	<u>TR-1</u>	<u>F-111</u>	<u>KC-135</u>
Sembach	Alconbury Bentwaters	Alconbury	Lakenheath Upper Heyford	Mildenhall

<u>F-15</u>	<u>F-16</u>	<u>F-4</u>
Bitburg Soesterberg	Torrejon Hahn Ramstein Spangdahlem	Spangdahlem

Figure 30. Normalized Energy Consumption for USAFE Airbases.

TABLE 3. VISITATION SCHEDULE: MAJCOMS AND AIRBASES.

Dates	Location	MAJCOM	Airbase	Other
16-17 May 90	Colo Spngs, CO	Space Command	Peterson AFB	NORAD
13-14 June 90	Omaha, NE	SAC	Offutt AFB	
17-19 July 90	Washington, DC	Hdqts, USAF	Bolling AFB	
		AFSC	Andrews AFB	
	Langely, VA	TAC	Langely AFB	
6-8 Aug 90	St. Louis, MO	MAC	Scott AFB	
		AFCC		
2-3 Oct 90	San Antonio, TX	ATC	Randolph AFB	
		ESC	Kelly AFB	
5-7 Nov 90	Dayton, OH	AFLC	WPAFB	ASD, SPOs, WADC, NASP
4-5 Dec 90	Honolulu, HI	PACAF	Hickam AFB	AAC
11 Feb 91	Boston, MA		Hanscomb AFB	ESD
12-14 Feb 91	Ramstein, GER	USAFE	Ramstein AFB	

C. AIRBASE ENERGY SYSTEM QUESTIONNAIRES

To understand existing airbase energy systems and determine how new technology energy systems might improve airbase energy capabilities, a database of airbase facility/utility energy systems is needed. (No comprehensive database documenting such systems for all USAF airbases is known to exist.) To obtain these data and establish such a database two questionnaires were developed — one for airbase level and one for MAJCOM level (Appendix C). With the assistance of each MAJCOM, questionnaires were sent to nearly all USAF airbases. When completed and returned the data will be entered into a comprehensive USAF Airbase Energy Systems database, which will be used to establish a baseline of airbase facility/utility energy systems.

D. ANALYSIS OF DATA AND ESTABLISHMENT OF BASELINE

1. Analysis of Energy Data for MAJCOM and Weapon Systems

A comparison of MAJCOM energy consumption and cost data is provided in Figures 31 through 34. Figure 31 shows that SAC is the largest overall energy consumer in the Air Force while Space Command consumes the least. However, PACAF appears to be the most energy-efficient when normalized only to airbase size (floor space) and Space Command the least (Figure 32). When normalized to both airbase size (floor space) and weather (degree-day factor), PACAF is again the most energy-efficient and Space Command and USAFE are the least (Figure 33). Airbase energy costs are greatest for SAC and least for the 11th Air Division of PACAF (formerly Alaskan Air Command) and Space Command (Figure 34).

The correlation of airbase energy consumption with Air Force weapon systems is somewhat less definitive. In general, airbases supporting weapon systems consume energy at rates ranging from 7 to 28 Btus/ft^2-DDF. The ranges of normalized energy consumption in 1989 for airbases supporting each type of system are included in Table 4.

TABLE 4. NORMALIZED AIRBASE ENERGY CONSUMPTION FOR MAJOR WEAPON SYSTEM CATEGORIES.

System Type	Btus/ft^2-DDF
Strategic Systems	18-23
Conus Tactical Systems	12-21
Military Airlift Systems	16-23
Air Training Systems	14-21
European Airbases	16-28
Pacific Airbases (Aircraft)	7-23
Pacific Airbases (Radar)	38
Space Systems	67

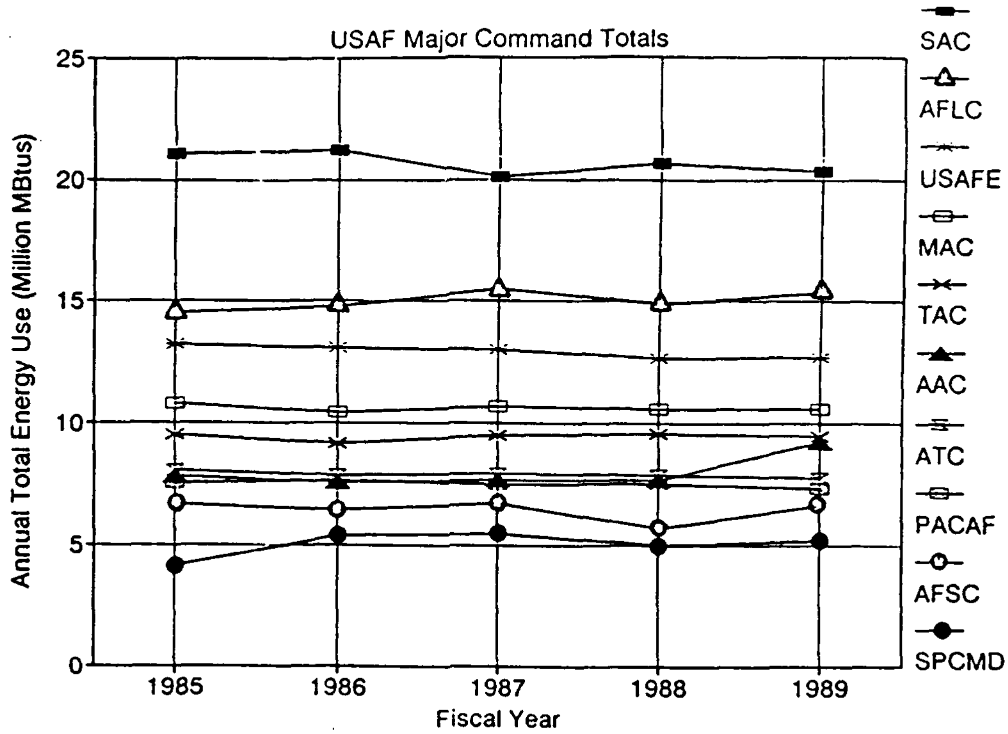


Figure 31. A Comparison of the Total Annual Energy Consumed by Each MAJCOM.

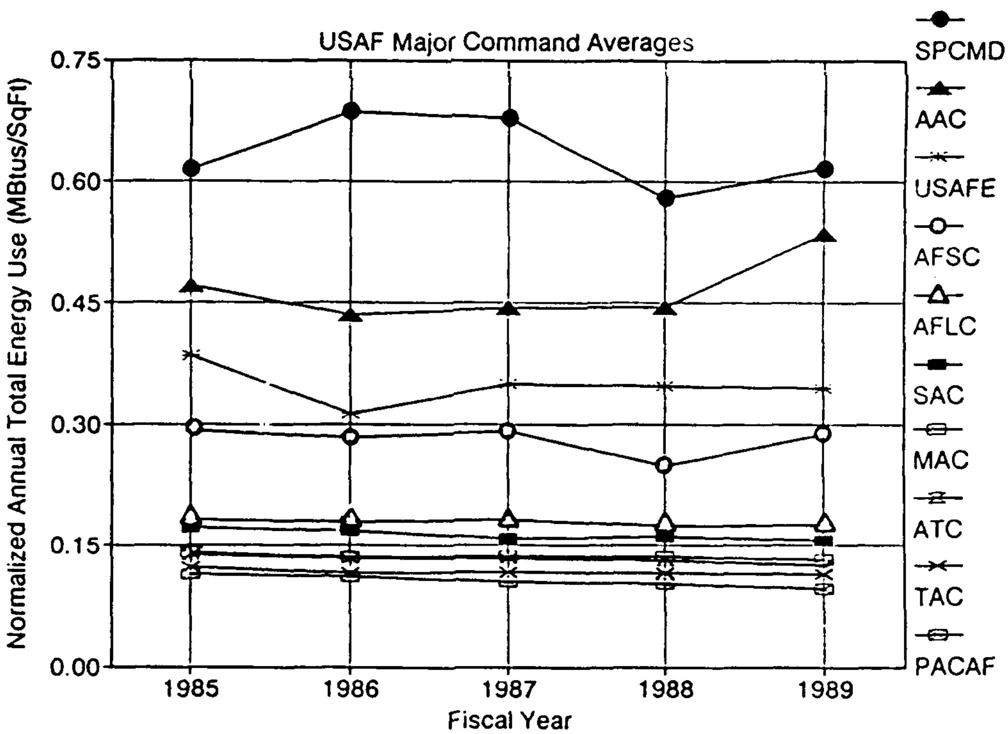


Figure 32. A Comparison of the Total Annual Energy Consumed, Normalized by Total Floor Space, for Each MAJCOM.

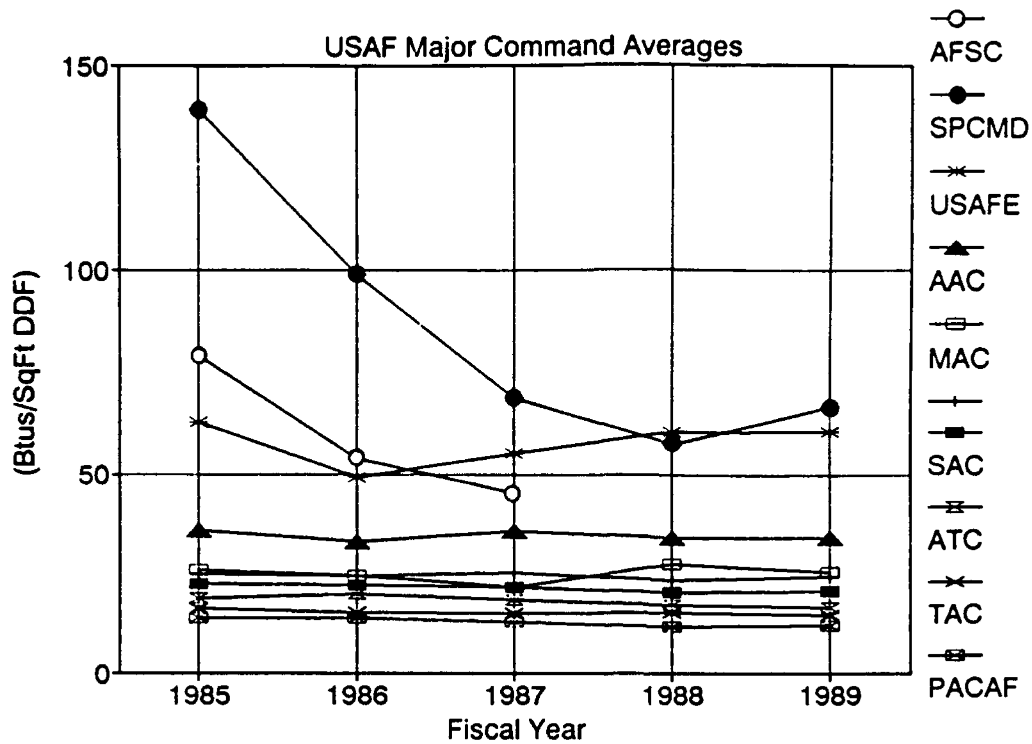


Figure 33. A Comparison of the Total Annual Energy Consumed, Normalized to Both Floor Space and Degree Day Factor, for Each MAJCOM. (Note: AFSC data for 1988 and 1989 are not available.)

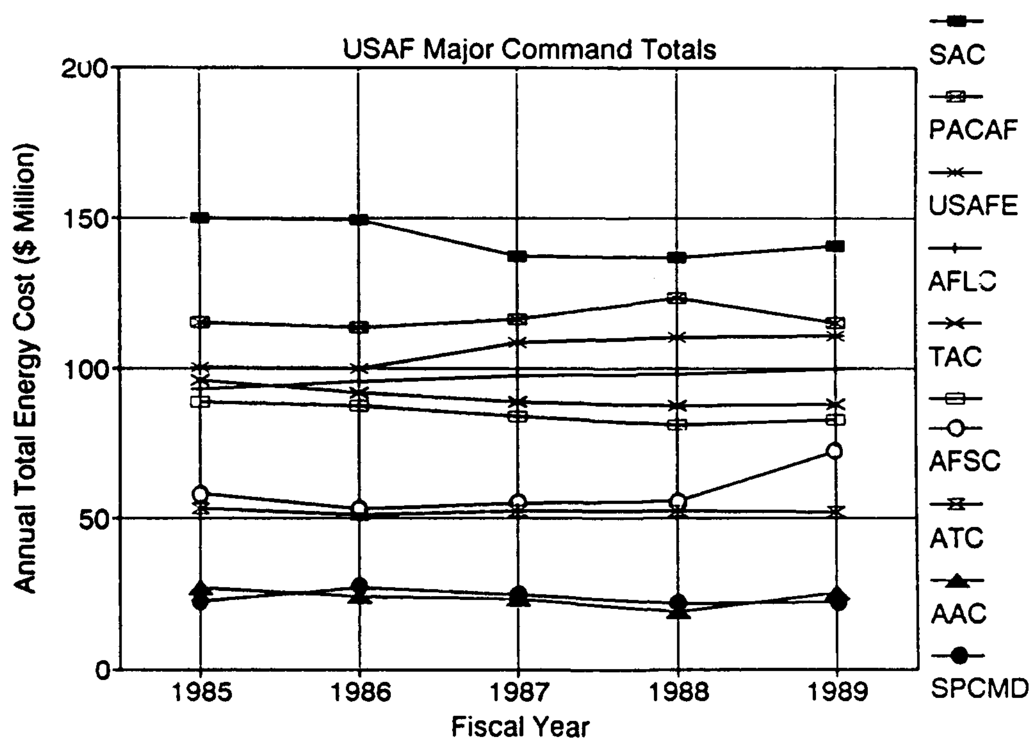


Figure 34. A Comparison of Total Annual Energy Cost for Each MAJCOM.

Although no absolute conclusion can be drawn regarding the correlations of weapon systems with airbase energy consumption, some indications can be observed. For strategic systems it appears that airbases supporting both B-1s and tankers consume less energy than those supporting B-52s and tankers. In the CONUS and in Europe, airbases supporting the F-16 consume less energy than those supporting the F-15; however, this conclusion does not hold for PACAF fighter bases though the data suggest an eventual convergence. The characteristics of the aircraft may explain that observation: (1) F-16s have only one engine while F-15s have two, and (2) the F-15 was developed when there was less emphasis on reliability/maintainability. Both characteristics result in increased maintenance man-hours and associated airbase energy consumption for the F-15. KC-135 and C-130 transport aircraft appear to consume less airbase energy than the C-5 and C-141 aircraft. Radar and data processing sites in PACAF (Alaska) consume far greater energy than aircraft bases, and installations supporting space activities tend to be very energy intensive.

2. Analysis of USAF Energy Consumption Data

An analysis summarizing the overall USAF facilities/utilities energy consumption and associated costs for the period 1985 through 1989 has been accomplished. The following specific data were examined to provide the results reported in Table 5:

- Total energy consumption
- Total facility floor space
- Total energy consumption normalized to floor space
- Total consumption of individual energy products
- Total energy costs
- Average energy costs

Total AF facilities/utilities energy consumption was slightly over 112.53 million MBtus in 1985 and remained relatively constant, diminishing only to slightly over 111.15 MBtus by the end of 1989 (Figure 35). Total facility floor space, increased steadily over this period from 700 to 775 million ft.^{2} (Figure 36). The resulting normalized energy consumption decreased from 0.160 to 0.144 MBtus/ft.^{2} (Figure 37), a 10 percent decrease over 5 years, which is substantially greater than the 1 percent/yr reduction required by the Defense Energy Program Policy Memorandum (DEPPM) 86-6. Figure 38 shows the total consumption of individual energy products over this period. Natural gas and electricity, the two most commonly used energy products, are consumed in approximately equal quantities. Natural gas usage has declined only

TABLE 5. TOTAL ENERGY CONSUMPTION AND ASSOCIATED COST BY MAJOR REPORTING UNITS.

	1985		1986		1987		1988		1989	
	MBtu	Cost ($)	MBtu	Cost ($)	MBtu	Cost ($)	MBtu	Cost ($)	MBtu	Cost ($)
AAC	7,821,844	27,326,334	7,542,311	24,319,538	7,668,042	23,432,585	7,701,177	19,208,553	9,232,535	25,469,759
AFLC	14,465,179	93,145,007	14,726,029	95,684,585	15,483,859	97,872,173	14,850,247	98,126,116	15,288,280	99,755,624
AFRES *	843,781	6,466,192	762,961	6,197,589	762,677	5,951,712	721,948	5,524,355	791,404	6,236,076
AFSC	6,663,994	58,210,285	6,446,157	52,917,462	6,694,346	54,823,698	5,711,921	55,579,912	6,633,210	71,966,470
ANG *	4,175,489	33,380,300	3,807,799	31,169,451	4,050,846	30,398,458	4,268,008	33,496,268	2,906,461	18,272,630
ATC	8,052,722	53,318,040	7,857,028	50,956,394	7,939,518	52,382,289	7,888,678	52,511,370	7,760,023	52,022,229
MAC	10,770,711	88,743,979	10,422,393	88,091,748	10,710,047	84,613,566	10,629,550	81,568,930	10,646,444	82,155,285
PACAF	7,520,993	115,393,752	7,629,109	113,565,455	7,486,304	116,179,877	7,536,762	123,551,286	7,331,369	114,976,220
SAC	21,055,512	150,010,435	21,173,478	149,420,465	20,107,969	137,182,762	20,671,882	136,737,506	20,337,987	140,871,945
SPACECOM *	5,538,469	29,579,292	5,551,564	28,218,050	5,626,508	25,955,269	5,279,361	22,152,751	5,293,246	20,068,739
TAC	9,511,454	95,989,908	9,150,730	91,982,927	9,501,318	88,861,205	9,571,215	87,686,255	9,466,264	87,781,454
USAFA *	1,155,144	5,905,715	1,092,529	5,629,281	1,110,957	5,616,252	1,104,369	5,388,067	1,132,026	5,840,582
USAFE	13,145,752	100,347,648	13,027,791	100,023,531	12,960,176	108,654,347	12,650,188	110,488,838	12,691,492	110,646,161
AU *	1,225,462	10,236,861	1,273,500	10,957,721	1,295,754	9,936,126	1,212,965	9,577,149	1,008,386	7,762,250
AFWD *	586,397	6,958,744	582,619	6,877,411	575,076	6,708,289	614,843	6,640,022	628,594	6,092,171
AF TOTAL	112,532,902	875,012,493	111,045,997	856,011,608	111,973,397	848,568,608	110,413,113	848,237,378	111,147,720	849,917,595

FROM DEIS II DATABASE FOR FY 1985-1989.

* Obtained from 22 February 1990 printout of DEIS II data, including estimates for missing data.

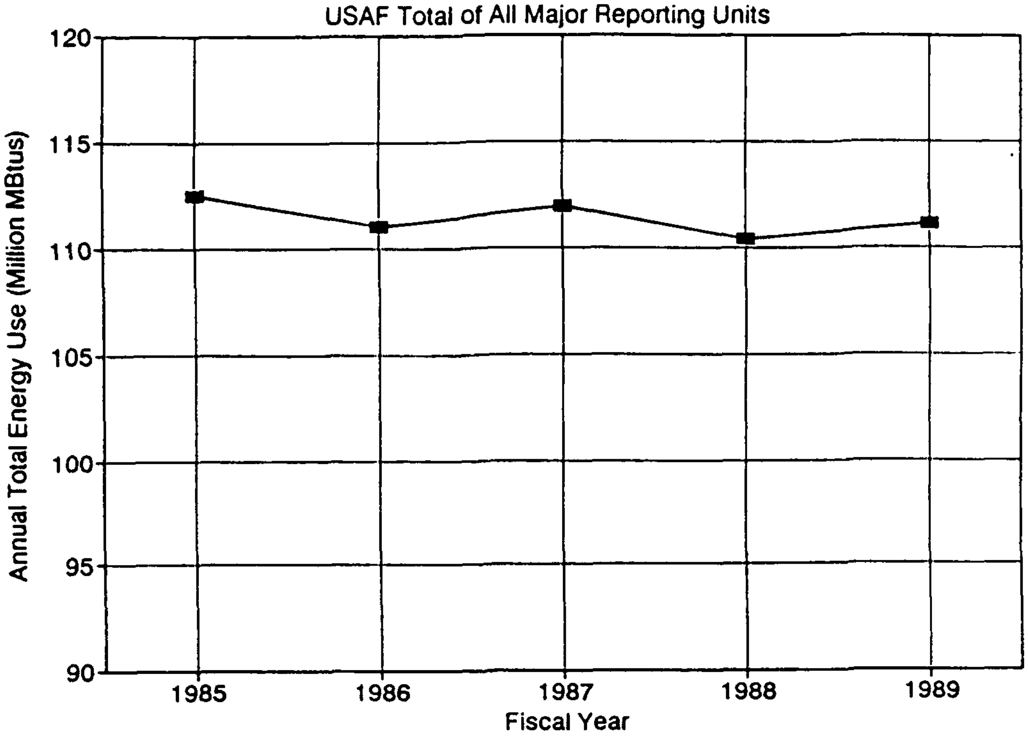


Figure 35. Annual Total Energy Usage by USAF.

slightly from around 37.2 million MBtus/yr in 1985 to approximately 36.6 MBtus/yr in 1989. Electric power consumption has increased from 34.6 to 36.6 MBtus/yr over this period, not a beneficial trend since it is the most expensive form of energy. The usage of diesel fuel (FSD), the third most common fuel, has declined steadily, a very beneficial trend. Consumption of the fourth most used product, coal, has been nearly constant at approximately 11 million MBtus/yr. Consumption of residual oils (FSR) also declined substantially at a rate almost parallel to the decline in diesel fuel.

The total AF annual cost for facilities/utilities energy, declined only slightly from \$875 million in 1985 to \$849 million in 1989 (Figure 39). The average cost for energy over this period also declined from \$7.76 to \$7.65 MBtu (Figure 40). These reductions in energy costs have resulted from several innovative energy purchasing and management activities, such as purchasing natural gas on the spot market, more stringent negotiations with utility companies, shifting consumption to non-peak hours, etc. However, there is a limit as to how much further these practices can be carried, which is reflected in the changing slope (upward trend) of the curves in both Figures 39 and 40.

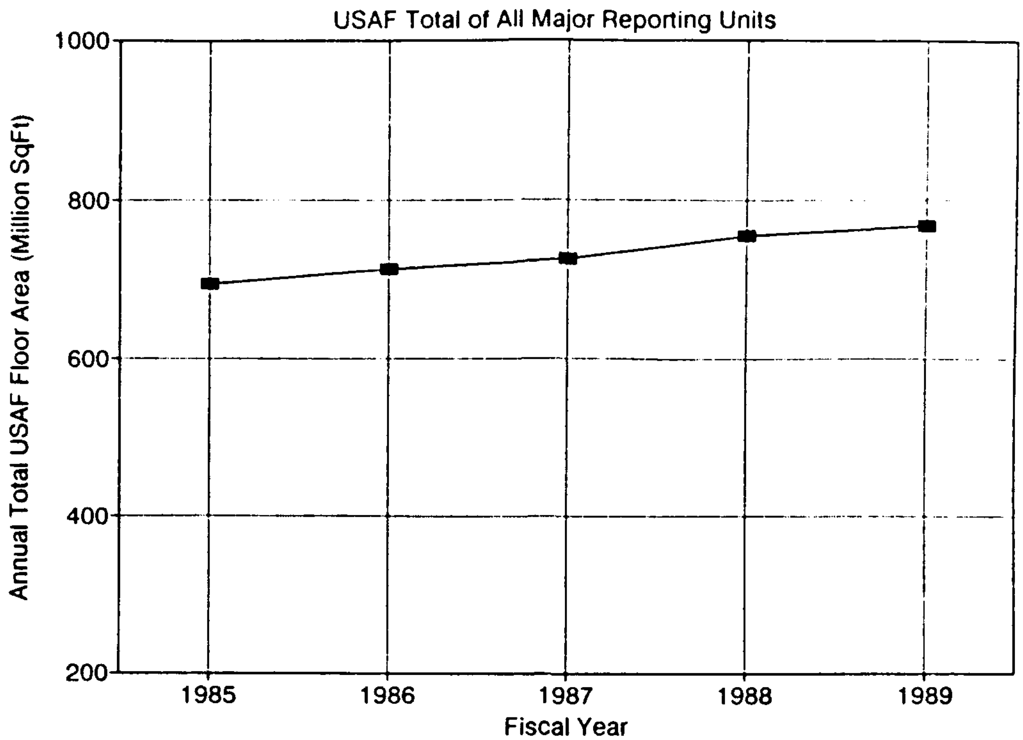


Figure 36. Annual Total USAF Floor Area.

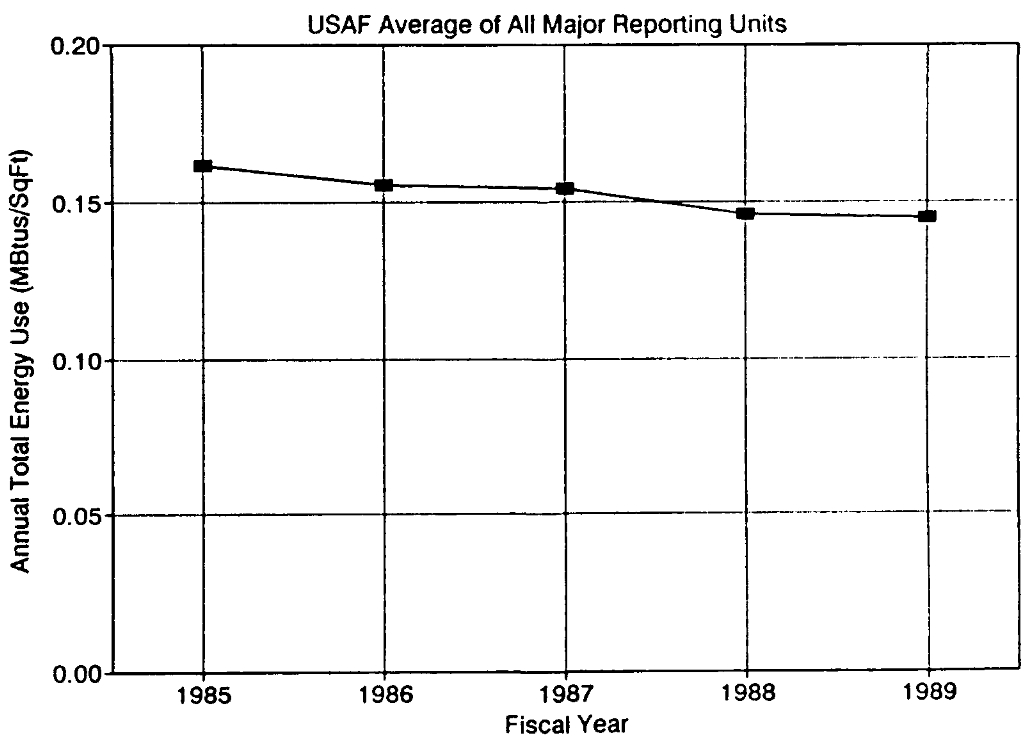


Figure 37. Annual Total USAF Energy Usage, Normalized to Floor Area.

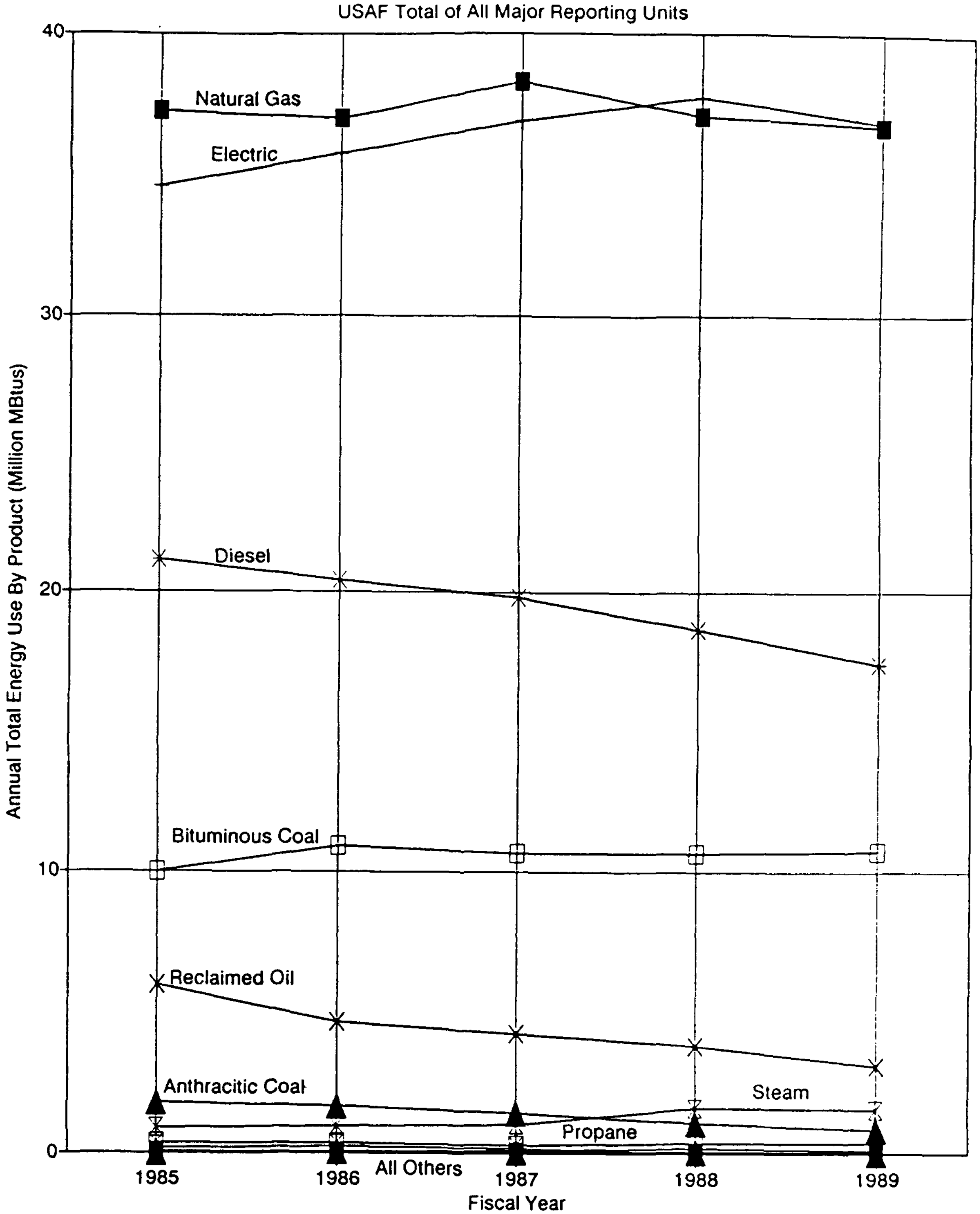


Figure 38. Annual Total USAF Usage by Energy Product.

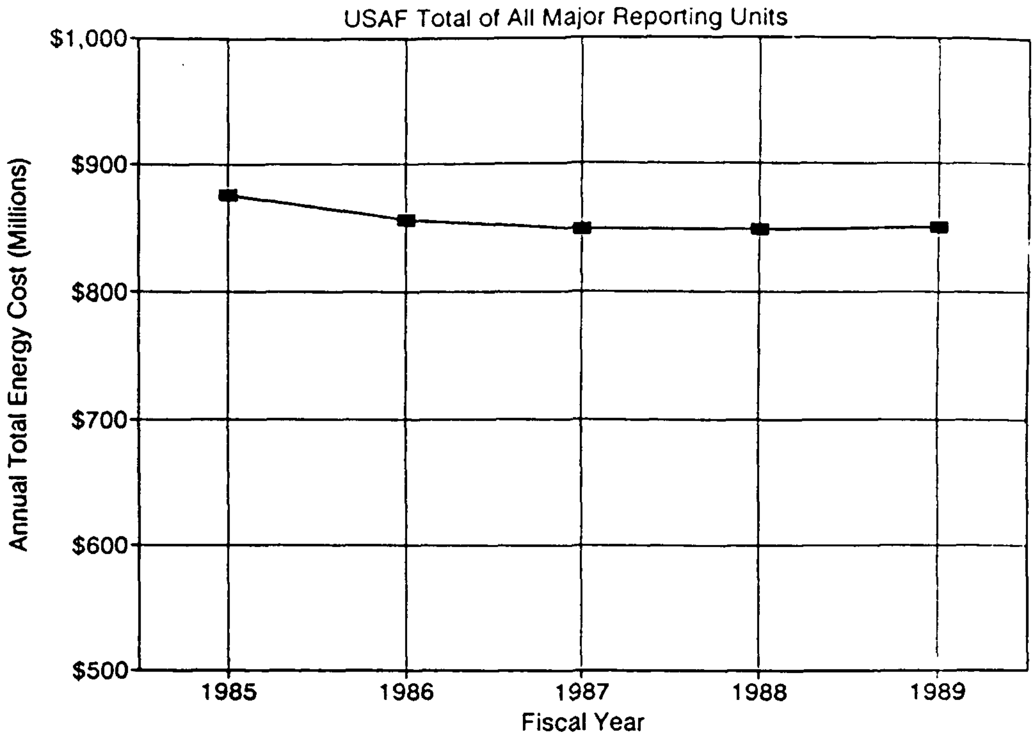


Figure 39. Annual Total USAF Airbase Energy Costs.

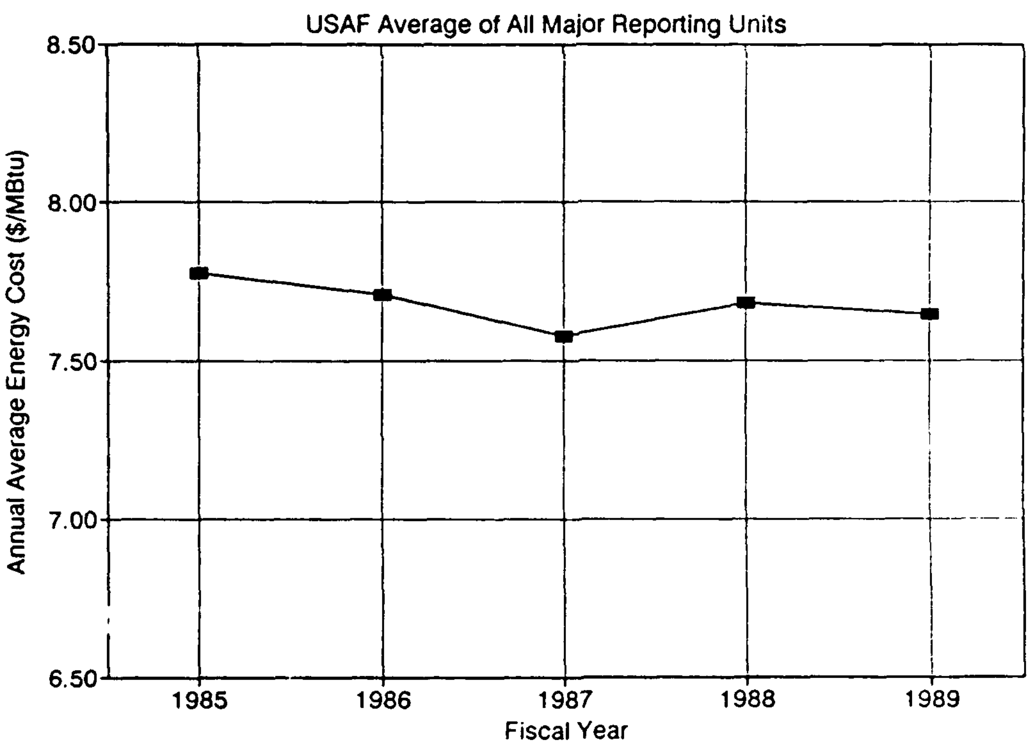


Figure 40. Annual Average USAF Airbase Energy Costs.

3. Projection of Past Trends to Form Baseline

The above trends have been projected based on the assumption that no significant changes will occur in either the Air Force or its way of doing business. It is further assumed that there will be no significant changes in the types of energy technologies employed, no new weapon systems, and no reduction in force and associated reduction in basing (Figures 35 through 38). These assumptions, though unrealistic, facilitate the establishment of baselines for examinations of potential future changes in the AF, as will be addressed in the following section. These projections of baselines are extended only to the year 2005 (near term plus mid term). Quantitative projections beyond that date would be highly questionable.

Projected total AF annual facilities/utilities energy consumption is shown in Figure 41. It is based primarily on a least-squares fit to the 1985-1989 data. FY 90 data, recently obtained from AFCESA, has also been plotted but was not included in the least-squares fit because it is considered an anomalous year due to Operation Desert Storm. Preliminary indications of FY 91 data (first 9 months) indicate an even higher consumption rate than FY 90, also as a result of Desert Storm. An estimated projection for FY 91 has been plotted. It was then assumed that by FY 92 AF activities will have returned to normal; therefore, a projected data point for that year has been plotted. For the remainder of the curve the fit to the 1985-1989 data has been extrapolated and then modified to reflect the rising national per capita trend for energy consumption (Reference 44). The projected total also reflects the inability of AF energy managers at existing airbase facilities and energy systems to continue to reduce consumption beyond some lower limit. Based on these assumptions, the curve must flatten and then eventually begin to rise.

Figure 42 presents a projection for AF facilities floor space, based on a least-squares extrapolation of the 1985-1989 data. Data for FY 90, recently obtained from AFCESA, have been plotted along with estimated projections for FY 91 and FY 92. Beyond FY 92, the least-squares fit curve has been modified to reflect the reality that the number of facilities cannot continue to increase forever. Even with business as usual, the amount of facilities floor space must eventually reach a maximum beyond which it cannot increase. The maximum value has been arbitrarily chosen so as not to exceed 812 million ft^2 beyond the year 2000.

Division of the above two data sets provides an estimate of the Energy Budget Figure (EBF — the facilities/utilities energy consumption normalized to floor area — MBtus/ft^2) that may be achieved by AF energy managers over this period (Figure 43). Also shown is the

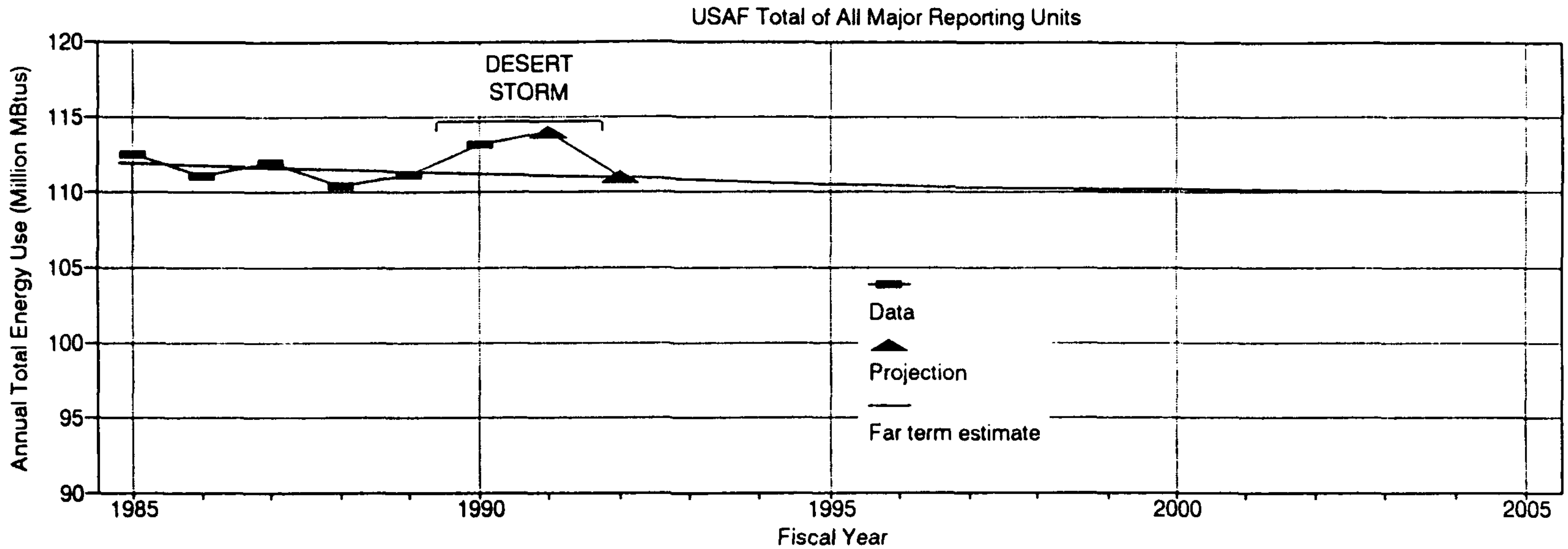


Figure 41. Projection of Annual USAF Total Facilities/Utilities Energy Consumption.

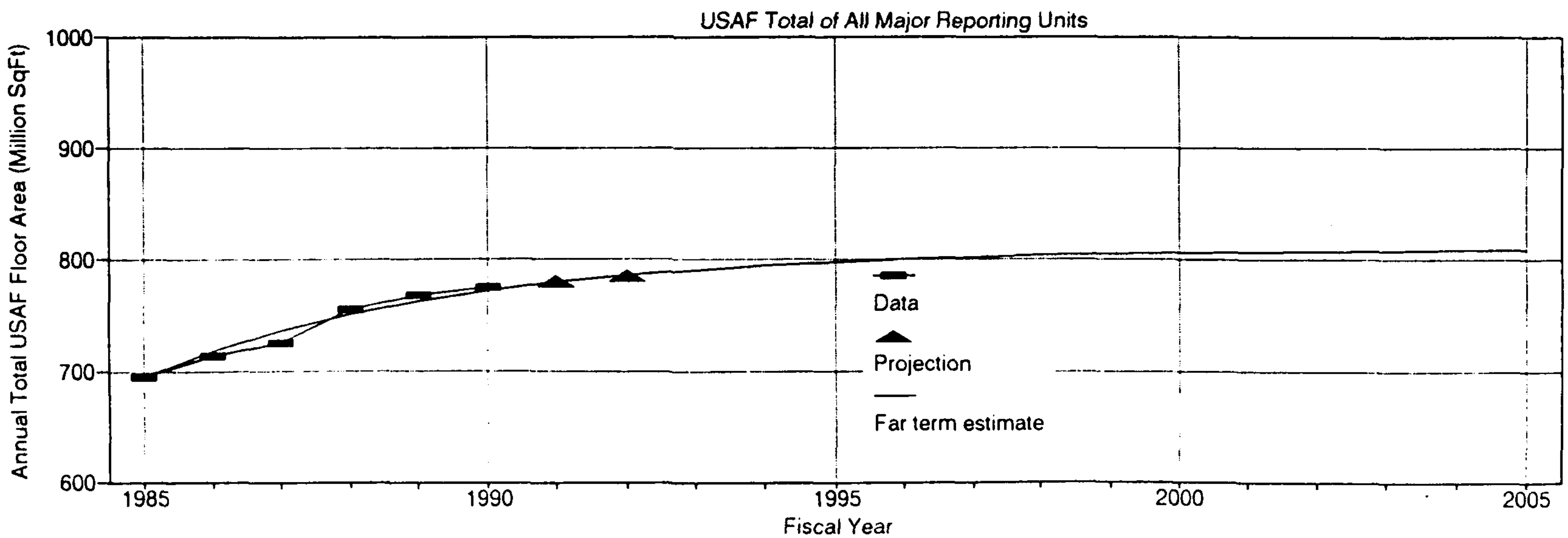


Figure 42. Projection of Annual USAF Total Facilities Floor Area.

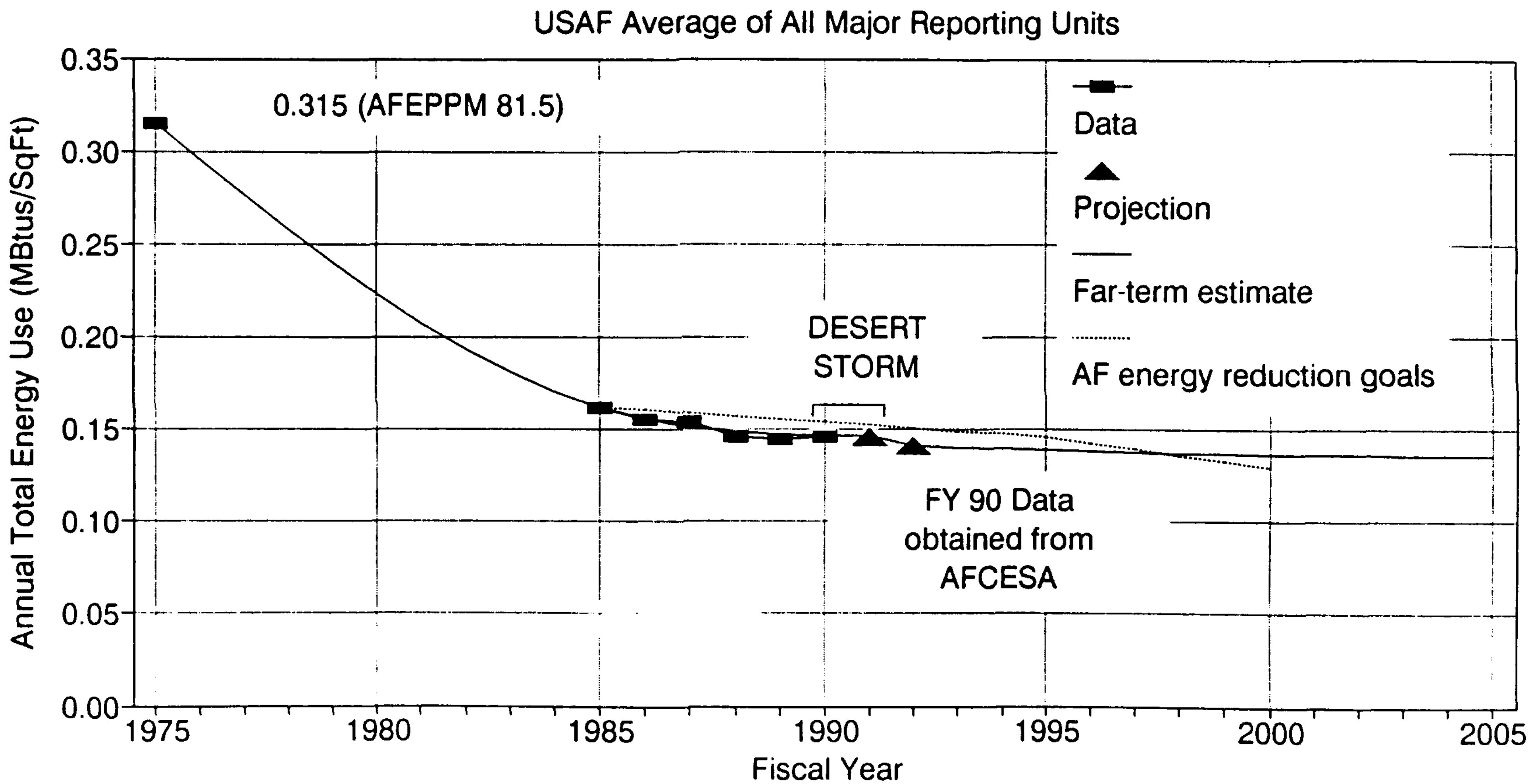


Figure 43. Projection of Annual Total USAF Energy Consumption, Normalized to Floor Area.

approved EBF for the USAF for FY 75 as documented in AFEPPM 81-5. A smooth curve has been drawn connecting this early data point with the 1985-1989 data and the projected curve to FY 2005. Also shown in Figure 43 are the AF energy reduction goals through FY 2000 relative to the FY 85 baseline. Without investments in more energy-efficient systems, it appears unlikely that AF energy goals can be achieved beyond FY 97.

There is little reason to expect the trends in energy product consumption to change very dramatically in the near and mid terms. Electricity and natural gas will probably remain the dominant energy products with consumption of electricity likely to increase. Petroleum fuels will probably continue to decline for facilities/utilities consumption with coal increasing slightly to make up part of the difference.

A projection of the average cost of energy until 2005, provided in Figure 44, is based on the changing slope of the curve from 1985 through 1989 (Figure 40), which indicates the curve should bottom within the near future. Escalation curves of 3 and 5 percent have been projected from this point. National energy cost trends have varied between these values over the past 20 years. By FY 2005 AF facilities energy could cost between $11.40 and $14.60 per MBtu. These escalation rates are considered low because the ongoing depletion of worldwide oil reserves and the greater enforcement of environmental restrictions are likely to drive world energy prices even higher over the next 30 years.

Using these average cost curves (Figure 44) and the annual consumption projected in Figure 41, a projected annual cost curve has been constructed (Figure 45). Based on this extrapolation AF annual facilities/utilities cost are expected to reach between $1.24 billion and $1.62 billion by 2005.

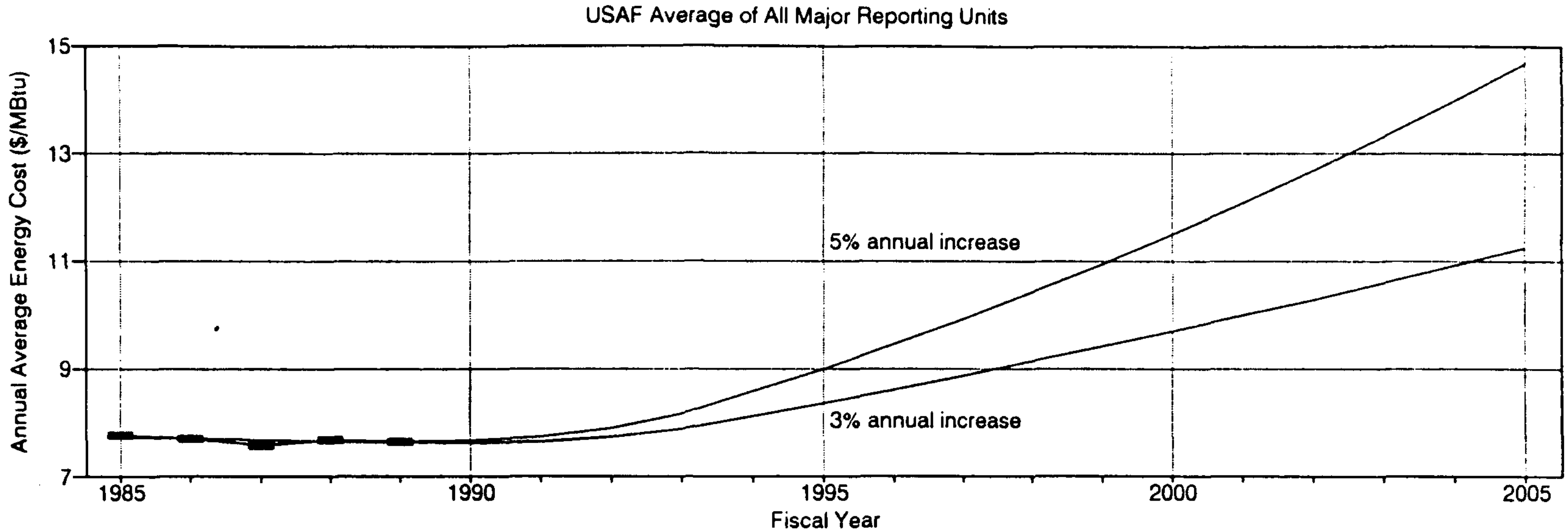


Figure 44. Projection of Annual USAF Average Facilities Energy Costs.

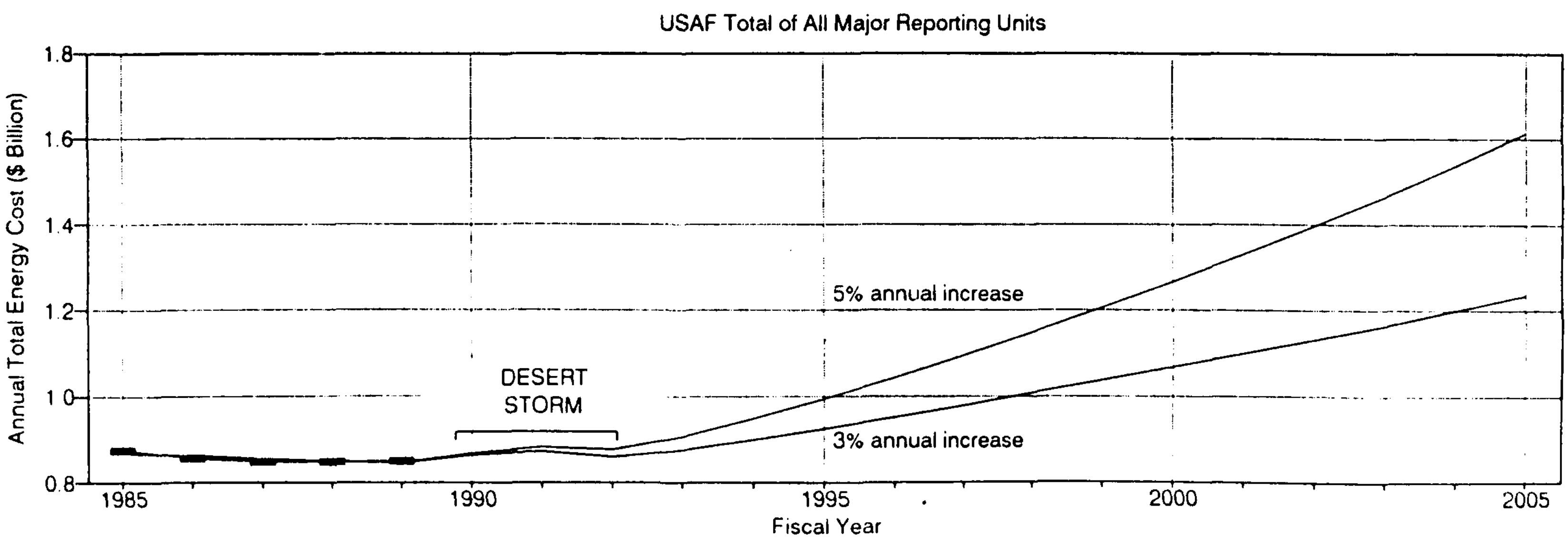


Figure 45. Projection of Annual USAF Total Facilities Energy Costs.

SECTION V

PROJECTED CHANGES TO BASELINE

A. PROJECTED WORLD ENERGY TRENDS

1. International Energy Trends

Many worldwide energy activities and difficulties discussed in Section III will continue, with increased intensity, over the next 30 years. Less developed countries will continue their struggle to gain parity with the more developed countries, a process that will continue to require more and more energy in increasingly sophisticated forms (Reference 45). This competition for the worldwide energy resources will undoubtedly drive all energy prices higher and higher.

With the declining oil supply over the next 30 years, competition for that increasingly valuable resource will become more intense. Prices will rise above affordable levels, and petroleum products will actually become unavailable more frequently at many locations. International conflicts, far more intense than the Gulf War, could break out over the rights to purchase and consume limited petroleum resources.

Finally, environmental pressures all over the world will force increased energy efficiencies on all major energy users, seriously constrain the use of some types of fuels, and force the increased use of renewable energy systems where renewable resources are abundant (Reference 46).

2. National Energy Trends

Recent trends at the national level to help reduce our nation's dependence on foreign oil will, over the next 30 years, continue to force reductions in our dependence on all types of petroleum products. As with the rest of the world, what these tailored programs do not achieve, the increased price and reduced availability are likely to.

As more states examine the indirect costs and penalties (called externalities) associated with various types of fossil fuels, increasing numbers of renewable energy systems will be employed. Recent DOE projections indicate by 2020 a third of our nation's energy will be supplied by renewables (Reference 47). Of that, a third (one ninth of total) will be provided by wind.

A revitalized US nuclear power industry seems likely within the next 30 years, especially if satisfactory methods for storing nuclear waste are operational. New, safer reactor designs (to be discussed in Section VI) and the accelerated licensing procedures proposed in Senate Bill 3.41 will help encourage that rebuilding process. There are already some indications that this revitalization process has begun (Reference 48).

B. NEW AIR FORCE SYSTEMS

1. Aeronautical Systems

A visit to the Aeronautical Systems Division (ASD) of the Air Force Systems Command was arranged, to determine the changes in facility/utility energy requirements that might be brought on by emerging aeronautical systems. Discussions with the ASD Advanced Development Office (ASD/XR) and the National Aerospace Plane (NASP) joint development office provided insight into AF aeronautical systems under development and concepts that are being studied for possible future systems. Additional information about basing concepts and airbase energy requirements for each of the airplanes currently under development was gathered during the visits to MAJCOMS to which such emerging systems will likely be assigned.

a. Air Force Aeronautical System Currently in Development

The following AF aeronautical systems, depicted in Figure 46, were affirmed to be at various stages of development and could affect future airbase energy requirements. (Although the systems discussed include those in which development and production have recently been completed, they could still affect airbase energy issues.)

(1) F-117A Stealth Fighter. This aircraft (Figure 47) is an extremely sophisticated, advanced technology fighter/bomber whose primary characteristic is an extremely low radar return, which permits it to fly through enemy airspace without being detected.

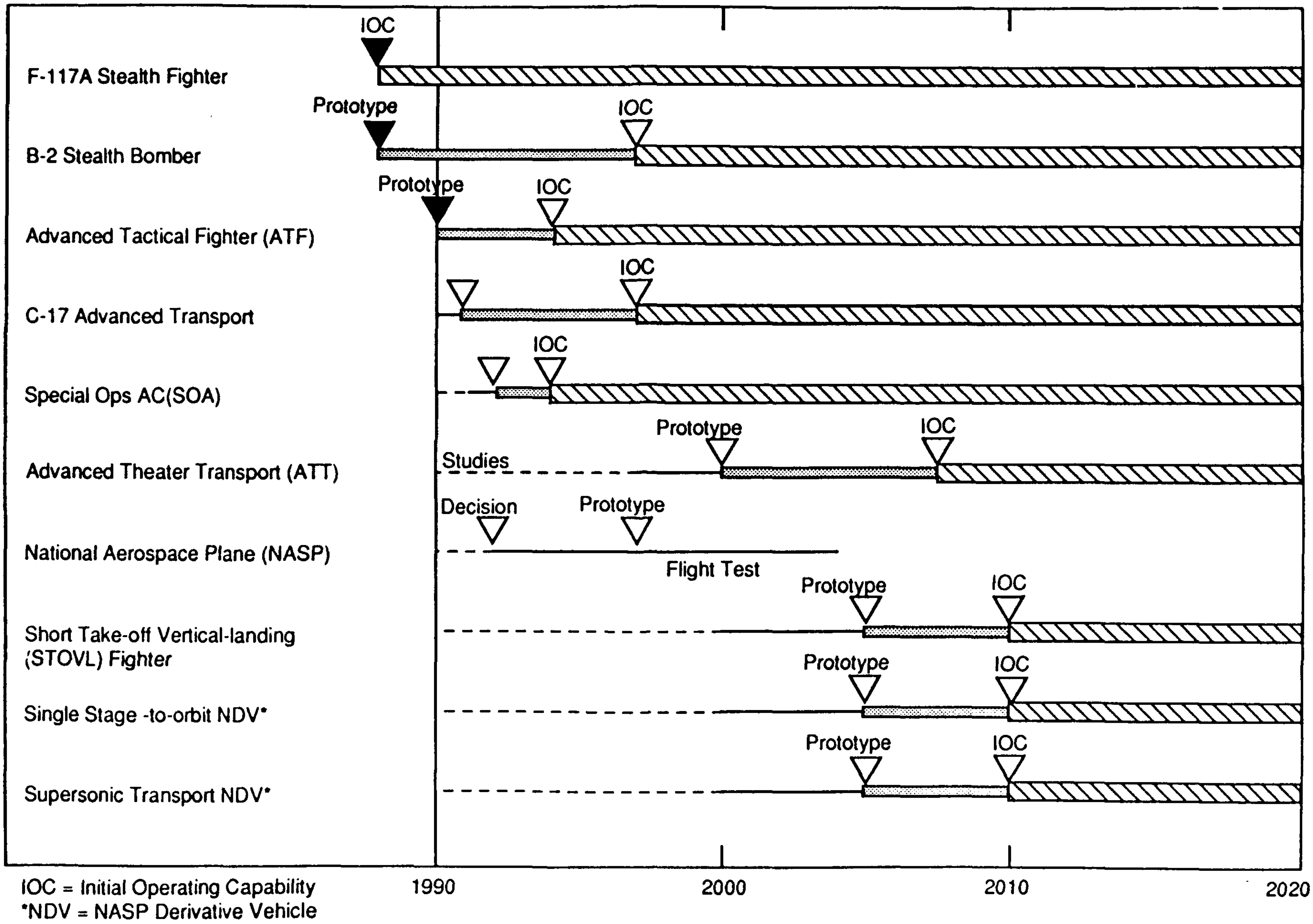


Figure 46. Aeronautical Systems Currently in Development or Being Studied.

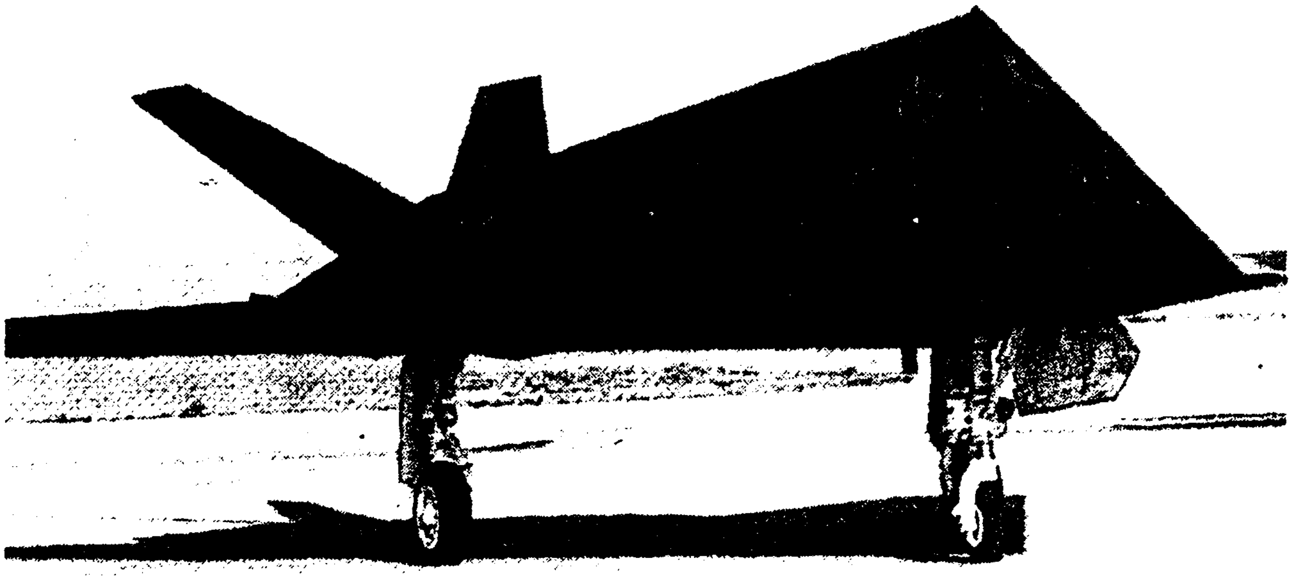


Figure 47. F-117A Stealth Fighter/Bomber.

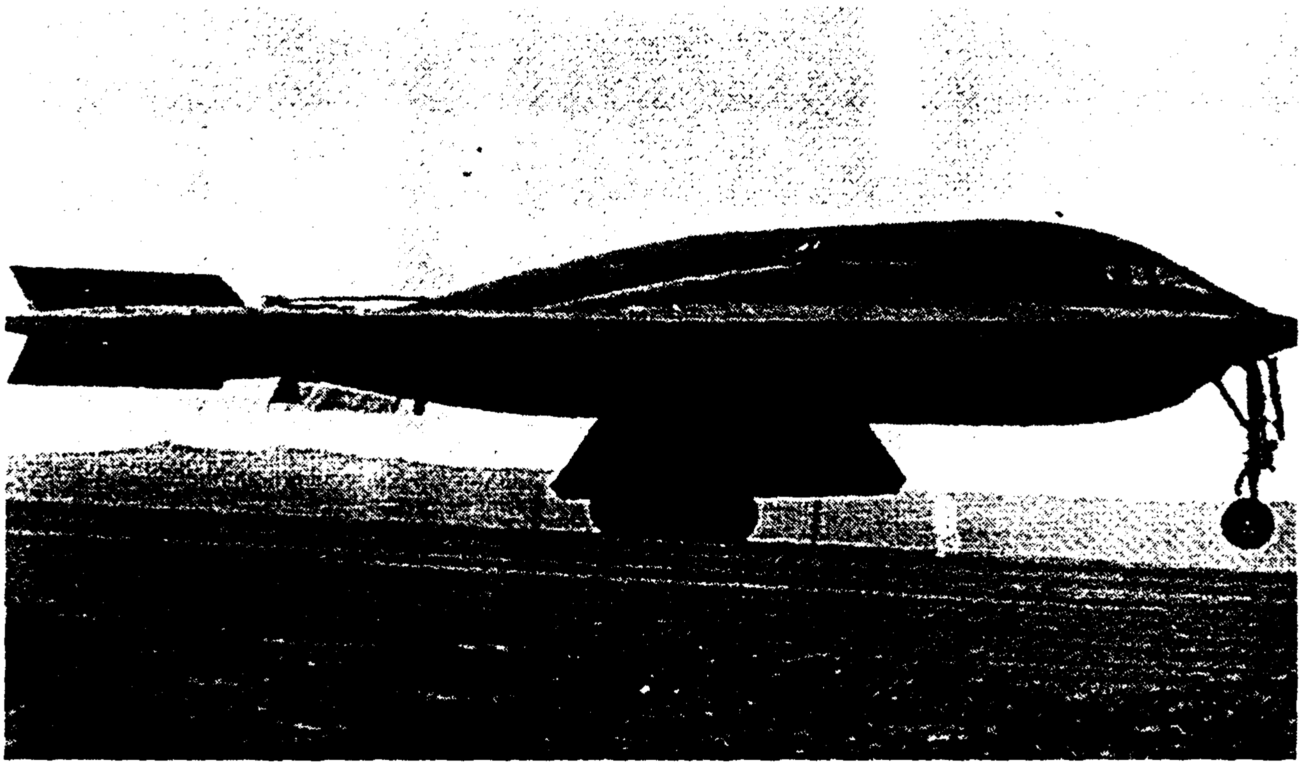


Figure 48. B-2 Advanced Technology Bomber.

It achieves this stealth capability through an array of advanced technologies, which includes unusual geometries, advanced composite, radar-absorbing materials, the location of the engine inlet ducts on the upper side of the aircraft, etc. Full development and production of the current planned purchase of these aircraft are complete, and the aircraft have already been heavily involved in combat in the Gulf War. Plans for permanently basing these airplanes at Holloman AFB, NM, have been announced by the Tactical Air Command (TAC). Because of concerns for possible ultraviolet light deterioration of the advanced-composite, radar-absorbing materials and the high cost of the aircraft, a decision to shelter the aircraft at all times when on the ground has been made. Required new construction facilities are being designed for Holloman AFB.

(b) B-2 Advanced Technology Bomber. This bomber (Figure 48) is being developed by a consortium of aerospace companies. Two prototype B-2s have been constructed and are now undergoing flight testing. The B-2 is an intercontinental strategic bomber with both nuclear and conventional weapon delivery capabilities. Like the F-117, the B-2 is constructed largely of radar-absorbing, advanced-composite materials and uses unusual geometries to enhance its stealth capabilities. If approved by Congress, the B-2 is scheduled to go into production in the mid-1990s and attain initial operating capability (IOC) in the late 1990s (mid-term). The Strategic Air Command, to which the B-2 will be assigned, has given preliminary indications that, if produced, the B-2s will initially be stationed at Whiteman AFB, MI, and one other airbase, yet to be announced. As with the F-117, SAC plans to shelter all of the B-2s while they are on the ground to help lower maintenance and increase reliability. Some additional energy costs will undoubtedly result from these additional facilities.

(3) F-22 Advanced Tactical Fighter. Two separate consortia of aerospace companies competed for the continued development and production of the Advanced Tactical Fighter (ATF). The two jet engine companies (General Electric and Pratt and Whitney) also competed for the continued development and production of a new jet engine to power the ATF. Two flying prototypes of each candidate ATF, one using each prototype engine, were constructed and flight tested. The AF recently announced the selection of the YF-22 (Lockheed, Boeing, General Dynamics) and the YF-119 (Pratt and Whitney) as winners of the competition (Figure 49). In addition to remarkable improvements in flight performance, the development team has revealed stealth characteristics and a planned use of substantial advanced composite, radar-absorbing materials.

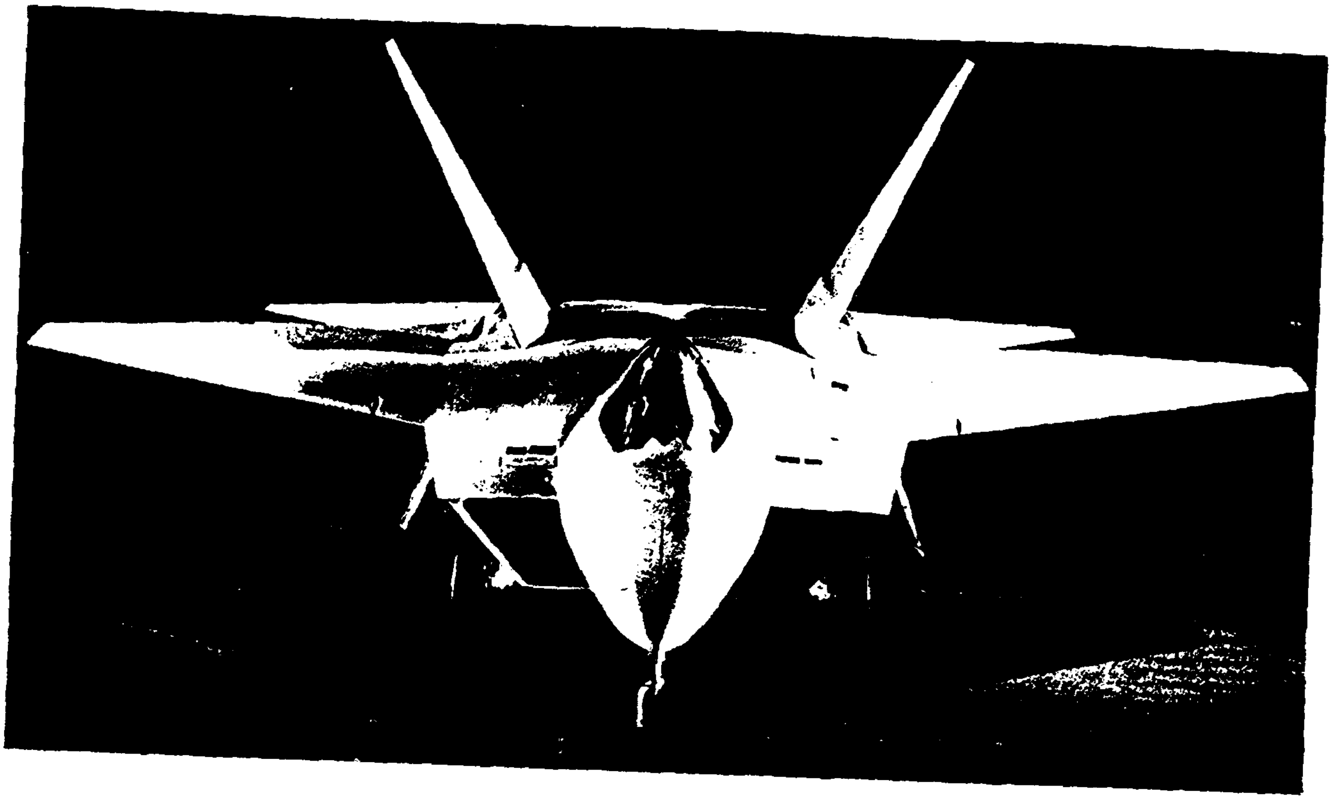


Figure 49. YF-22 Prototype Advanced Tactical Fighter.

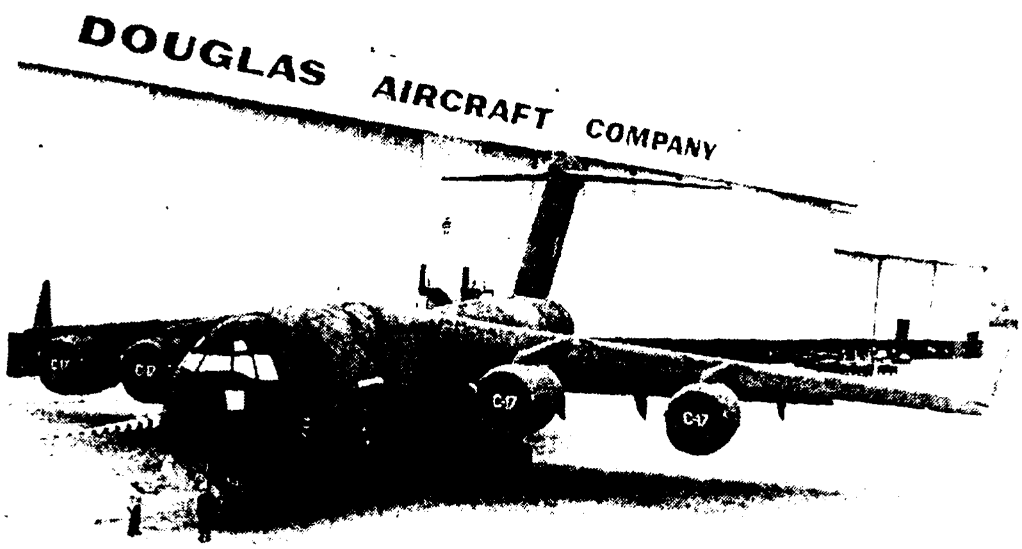


Figure 50. YC-17 Advanced Tactical Prototype.

Future ATFs will likely be assigned to the Tactical Air Forces (TAFs — Tactical Air Command, Pacific Air Forces, USAF Europe) and are scheduled to attain IOC in the mid-1990s (mid term). The TAFs have not yet revealed any plans for basing ATF aircraft should they be produced. It is likely that, similar to the F-117 and the B-2, the ATFs will be sheltered most of the time when on the ground.

(4) Advanced Tactical Airlifter. The final new aircraft system currently under development is the C-17 Advanced Tactical Airlifter (Figure 50). The first prototype aircraft is scheduled to begin flight testing in late 1991. It is planned to achieve IOC in the late 1990s (mid term). The C-17 is similar in size to the C-141 but will probably replace some of the aging C-130 aircraft. The C-17 will require few special new facilities at host airbases.

b. Potential AF Aeronautical Systems

The following possible future AF aircraft are currently being studied by ASD/XR; however, no firm plans for development or production have been announced.

(1) Special Operations Aircraft. A special operations aircraft (SOA) is being studied for autonomous operations from bare bases. The SOA would use ordinary jet fuels and would require no new or special facilities. It could be a vertical-lift type aircraft that would operate much like the AV8-B Harrier aircraft of the US Marines. It may require highly mobile basing equipment including mobile airbase power systems. The projected IOC for an SOA is 1996 to 1997 (mid term).

(2) Advanced Theater Transport. An advanced theater transport (ATT) aircraft is being studied as a followon aircraft for the C-130. It is envisioned to be a direct combat support airlifter with short takeoff and landing (STOL) or vertical/short takeoff and landing (VSTOL) capabilities. The aircraft would use ordinary jet fuels and would be constructed largely of advanced-composite materials. A flying prototype could be ready as early as 2000; the projected IOC is 2008 (far term).

(3) Short TakeOff/Vertical Landing Fighter Aircraft. Concepts for a short takeoff/vertical landing (STOVL) fighter aircraft are being studied and compared with more conventional fighter aircraft. Such an aircraft could be used by the AF for close air support much like the Marines use the AV8-B Harrier. It would likely be constructed largely of advanced-composite materials and use ordinary jet fuels. An IOC date in 2010 is envisioned (far term).

(4) National Aerospace Plane Concepts Exploration. The development of the National Aerospace Plane (NASP), a joint NASA/AF project now ongoing at Wright-Patterson AFB, OH, is advancing a number of technology concepts that have been in the R&D stage for several years. Examples are the following:

- Manned hypersonic flight in an aircraft-like vehicle
- Earth-orbiting space flight beginning with conventional aircraft takeoff
- Use of hydrogen (H_2) as the complete fuel for an aircraft-like space vehicle
- High temperature capability airframe materials and structures permitting hypersonic flight by aircraft-like vehicles

Successful completion of the NASP project will likely spawn several NASP derivative aircraft, some military and some conventional. Two military NASP derivative vehicles (NDV) are being studied by ASD/XR. One would be a supersonic transport/cargo aircraft for airlifting cargo and personnel from the interior of the CONUS to overseas airbases, nonstop, in only a few hours. This transport aircraft would operate at Mach 2.5 to 3 and use only standard jet fuels. A second, single-stage-to-orbit, hypersonic aircraft would operate at Mach 5 to 6 and use conventional jet fuels, liquid hydrogen, and liquid oxygen. The potential IOC time for such aircraft is 2010 (far term). Accomplishment of this goal will require more affordable supplies and better operating procedures for liquid hydrogen.

2. Space Systems

To learn about future space systems that could affect airbase facility/utility energy consumption and costs, advanced planning personnel at Air Force Systems Command, Space Systems Division (SSD/XR), were contacted. Vehicles in space such as satellites are the primary systems with which SSD works. These, of course, have only minimal influences on airbase energy consumption. However, space launch vehicle and launch preparation facilities can lead to significant energy consumption and high costs. Only one set of future space launch vehicles was identified.

Following recent guidance from the National Space Council the Air Force and NASA have teamed to develop a National Launch System (NLS) that can fulfill the space launch needs of both agencies. Now in its advanced planning stages, the NLS will consist of the current fleet of reusable space shuttles augmented by an expendable launch system. This expendable launch system will have a common core of a LH /LOX primary booster capable of launching payloads in about the same weight range as the shuttle (50,000 pounds). Since it will be unmanned it will cost much less than the shuttle to place an object in orbit. A heavy lift version (150,000-pound payload) of this expendable system will be achieved by strapping onto the common core a pair of solid rocket boosters similar to those used on the shuttle. The expendable launch vehicle portion of the NLS is planned to become operational between FY 2000 and 2010. A launch pad, launch equipment, and payload preparation facility construction worth $2.5 billion will be accomplished at both Cape Canaveral and Cape Kennedy to accommodate these new systems.

Only one new intercontinental ballistic missile (ICBM) system, a small ICBM called "Midgetman," is under development. It is a smaller ICBM intended to carry only one or two nuclear warheads and to be launched from a hardened mobile launcher. The prelaunch survivability of the launcher is greatly enhanced by its ability to roam randomly over wide areas on southwestern airbases. The system has not been well supported by Congress and its future is highly uncertain. No other new ICBM systems are being seriously considered at this time.

The Peacekeeper rail-garrison system is not a new ICBM but a proposed mobile-basing system for the Peacekeeper ICBM. The 50 existing Peacekeeper missiles are currently based in 50 former Minuteman silos in Wyoming. The rail-garrison basing plan is to place two Peacekeeper missiles in a railroad car from which they could be launched. Several other support cars would accompany the launch car to form a mobile ICBM train. Several such trains would be housed in a garrison to be constructed on an existing military base, such as Francis E. Warren AFB, WY. Several such garrisons would be constructed at different locations. Upon notice of increasing world tensions or any specific threat, the trains would depart from the garrisons and move randomly on the national railroad system to achieve pre-launch survivability. Upon receiving properly verified notification and instructions the train would stop and launch its missiles. The missiles could be launched from the trains while they are in the garrisons if necessary. There is also substantial uncertainty as to the future of this system.

3. Electronic Systems

The Electronic Systems Division (ESD) of Air Force Systems Command was visited, to determine possible changes in facility/utility energy requirements that might result from new AF electronic systems. A number of new or emerging electronic systems were discussed including the new phased-array radar systems (Pave Paws), and Over-the-Horizon Radar (OTHR). It was learned that nearly all of the new, large electronic systems that could impose significant energy requirements on host airbases are already nearing completion. No other new systems of significant size are currently being planned for development and acquisition by the Air Force. Consequently, no significant increases in airbase energy consumption as a result of new, large electronic systems can be expected in the foreseeable future. In fact, there is clear evidence that as new, solid-state electronic systems replace older tube-type systems, significant reductions in energy consumption can be expected.

4. Projected Airbase Energy Requirements

From the information gathered and analyzed above it appears that changes to airbase energy requirements resulting from new AF systems anticipated to emerge within the next 30 years will be minimal. The carport-like shelters being constructed for the F-117 stealth fighter at Holloman AFB, NM, will use only small amounts of additional energy. When the F-22 ATF enters the operational Air Force, it too will likely be sheltered under structures similar to those for the F-117 and thus will require only small increases in energy consumption. Any increases, however, will be mostly offset by the retirement of the F-15 since the F-22 should require fewer maintenance manhours than the F-15.

The B-2 will be housed in hangar-like facilities complete with refueling and servicing capabilities. These facilities will undoubtedly consume more energy than if the planes were parked unsheltered on the ramp as are the current bomber aircraft. Again, however, the increased energy consumption could be offset by reductions in the overall bomber force brought on by the demise of the Warsaw Pact and reduced East-West tensions. Other aircraft projected for future development also show no requirement for increased airbase energy consumption. Thus, few significant increases in airbase energy consumption from aeronautical systems can credibly be forecast.

No significant changes in airbase energy consumption resulting from new Air Force electronic systems were discovered. The same is true of space systems except that a greater requirement for onbase supplies of liquid hydrogen and liquid oxygen will occur with the emergence of the National Launch System, the National Aerospace Plane, and any derivatives of these.

It is unlikely that there will be significant changes to airbase energy requirements should either the Midgetman ICBM or the rail-garrison Peacekeeper systems be developed and deployed for two reasons: (1) the number of missiles and warheads that can be in service at any time is limited by treaty, and (2) for every new facility that would be constructed for either of these systems, an existing facility would probably be shut down. Thus, the facilities/utilities energy consumption should remain nearly constant. There would be, however, a substantial increase in the consumption of transportation fuels (diesel) for the trains or the hard mobile launcher.

C. REDUCTIONS IN FORCES AND BASE CLOSURES

The remarkable geopolitical changes that have occurred in eastern Europe and the Warsaw Pact nations in the past several years have greatly reduced the military threat and eased the tensions in that part of the world. Although still very strong militarily, the Soviet Union is having extreme economic difficulties and internal political problems. At this time they do not appear to pose a major threat to the United States or other members of the NATO alliance. This lessening of world tensions and the pressure of a severe national debt has caused Congress to mandate reductions and impose severe cuts on the military. In spite of brilliant performances in the recent Gulf war, substantial reductions in force structure are being planned. Instead of the 36 tactical fighter wings currently in service, it now appears that the AF will reduce its tactical force structure to 28 wings by 1996 (Reference 49). Reductions in Reserve forces are being discussed as well.

As a counterpart to the reductions in force structure, a number of military bases will likely be closed. Secretary of Defense Cheney has recently announced a plan to close 31 military installations by 1998, 13 of them being Air Force (Reference 50). These along with the five AF base closures previously announced (1989) will mean an overall 7.3 percent reduction in AF installations within the next seven years. A list of CONUS installations currently being considered for closure is provided in Table 6, along with 1989 energy consumption and floor space for each. Although there will be some buildup (and increased energy consumption) at the few bases that pick up the mission of some of the closing bases, it should result in a substantial reduction in airbase energy consumption and associated costs. In discussions with advanced planning personnel at USAFE Headquarters, it was learned that a substantial reduction in airbases is being considered. A 40 percent USAFE airbase reduction could occur over the next 10 years. Similarly, during discussions with PACAF planning personnel, the possibility of additional airbase closures was disclosed. Reductions in Korea, Japan, and the Philippines are being considered. The number of PACAF airbases and other installations could shrink by as much as 50 percent over the next 30 years; however, the 11th Air Division of PACAF (formerly Alaskan Air Command) is not being considered for airbase reductions. In fact, additional AF units are currently scheduled for deployment to that area. Estimated reductions in both energy and floor area resulting from base closures in PACAF and USAFE are also shown in Table 6.

TABLE 6. USAF INSTALLATIONS IDENTIFIED FOR POTENTIAL CLOSURE.

Installation	1989 Energy Consumption MBtu/yr	Floor Area (ft^2)
CONUS (to be closed over 7 yrs)		
Williams AFB, AZ (ATC)	300,000	2,500,000
Eaker AFB, AK (SAC)	400,000	3,200,000
Castle AFB, CA (SAC)	400,000	3,333,333
Lowry AFB, CO (ATC)	970,000	6,466,667
Moody AFB, GA (TAC)	200,000	2,222,222
Grissom AFB, IN (SAC)	800,000	4,000,000
England AFB, LA (TAC)	250,000	2,500,000
Loring AFB, ME (SAC)	1,150,000	6,388,889
Wurtsmith AFB, MI (SAC)	660,000	4,888,889
Myrtle Beach AFB, SC (TAC)	260,000	2,888,889
Bergstrom AFB, TX (TAC)	400,000	3,636,364
Carswell AFB, TX (SAC)	450,000	3,750,000
Chanute AFB, IL (ATC)	1,250,000	6,944,444
Norton AFB, CA (MAC)	600,000	6,521,739
Pease AFB, NH (SAC)	700,000	4,117,647
Mather AFB, CA (TAC)	480,000	4,363,636
George AFB, CA (TAC)	430,000	4,777,778
Richards-Gebaur AFS (AFR)	20,000	400,000
Rickenbacker AGB (ANG)	18,855	1,848,529
	9,738,855	74,749,026

PACAF

50% Installation Reduction in 30 years (assume 25% by 2005)

7.4×10^6 MBtu/yr $\Rightarrow$ 3.7×10^6 MBtu/yr $= 3.7 \times 10^6$ MBtu/yr reduction

46,250,000 ft^2/yr $\Rightarrow$ 23,125,000 ft^2/yr = 23,125,000 ft^2/yr reduction

USAFE

32 Installations $\Rightarrow$ 20 Installations over 10 years (by 2001)

12.7×10^6 MBtu/yr $\Rightarrow$ 7.94×10^6 MBtu/yr $= 4.76 \times 10^6$ MBtu/yr reduction

100.79×10^6 ft^2/yr $\Rightarrow$ 62.996×10^6 ft^2/yr $= 37.797 \times 10^6$ ft^2/yr reduction

D. AIRBASE ENERGY PROJECTIONS

1. Adjusted Projections of Energy Requirements

The previously constructed baseline projection of AF facilities energy consumption (Figure 41) was used to develop an adjusted projection, which takes into account the estimated energy effects of airbase closures, the increases or reductions in energy consumption brought on by emerging or retiring weapon systems, and the potential effects of the President's Executive Order and the new DOD energy policy memorandum. The potential energy effects of each of these changes were overplotted on the previous baseline projection.

By summing the 1989 energy consumption of each of the CONUS airbases slated for closure (Table 6), a first level projection of reduced energy consumption and floor space is obtained. An estimated energy reduction of 9.7 million MBtus/yr projected to 2005, which will result from the CONUS base closures, is presented along with estimated reductions from closures of USAFE and PACAF installations (Figure 51). Projected reductions in total facilities floor space because of these airbase closures are shown in Figure 52.

By dividing the data from Figure 51 by the data from Figure 52 an estimate of the projected EBF (normalized energy consumption, MBtus/ft^2) was obtained (Figure 53). The dotted line in Figure 53 represents the AF energy reduction goals, relative to FY 85, as required by the new DoD energy policy. Even with the airbases selected for closure, AF goals for decreased energy consumption may not be met beyond FY 97 with existing facilities and energy systems.

Finally, the projected energy consumption data with base closure (Figure 51) were multiplied by the projected average energy costs provided earlier (Figure 44) to obtain totals for AF facility energy costs following base closure (Figure 54) using both 3 and 5 percent per year escalation rates. With projected base closures the total AF facility energy costs should drop from \$1.24 - \$1.6 billion to \$1.07 - \$1.37 billion by FY 2005.

2. Projections of Energy Deficiencies/Difficulties

From the analyses performed in this and the preceding sections several major energy difficulties to be faced by airbase energy managers can be forecast. First, as shown in Figure 53, it seems unlikely that the AF will be able to meet its mandated energy reduction beyond FY 97 with current facilities and existing energy systems.

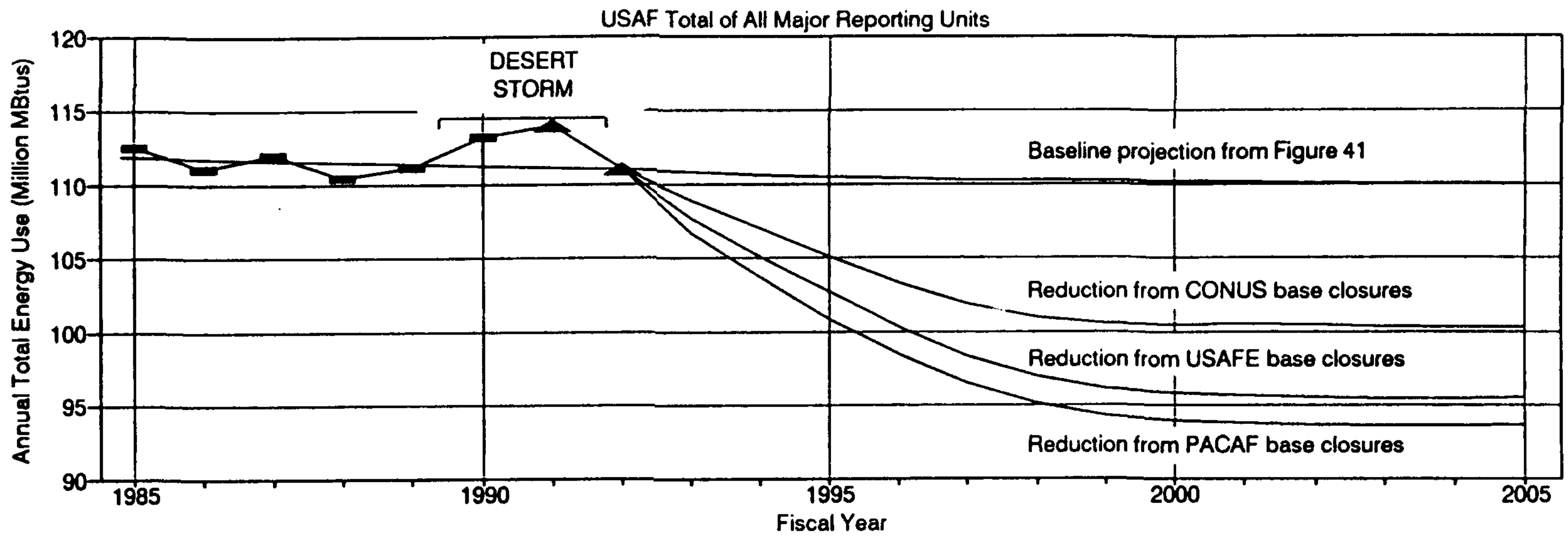


Figure 51. Projected Annual USAF Facilities *Energy Consumption* Following Potential Airbase Closures.

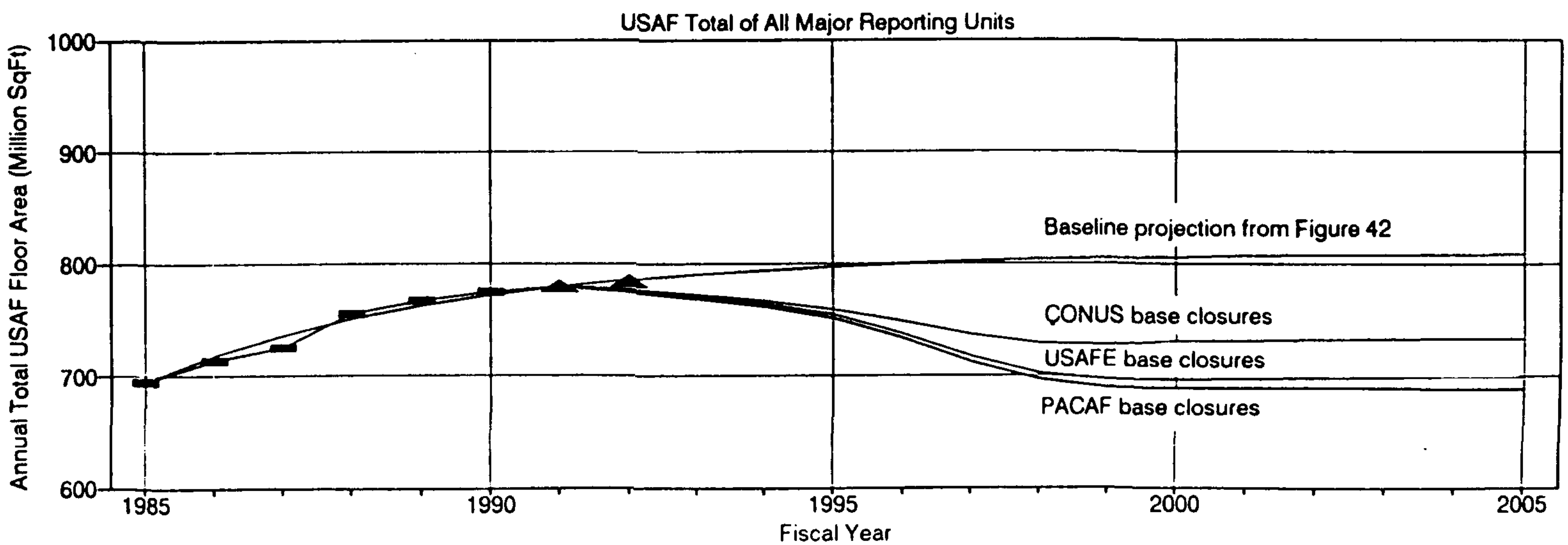


Figure 52. Projected Annual USAF Total Facilities Floor Space Following Potential Airbase Closures.

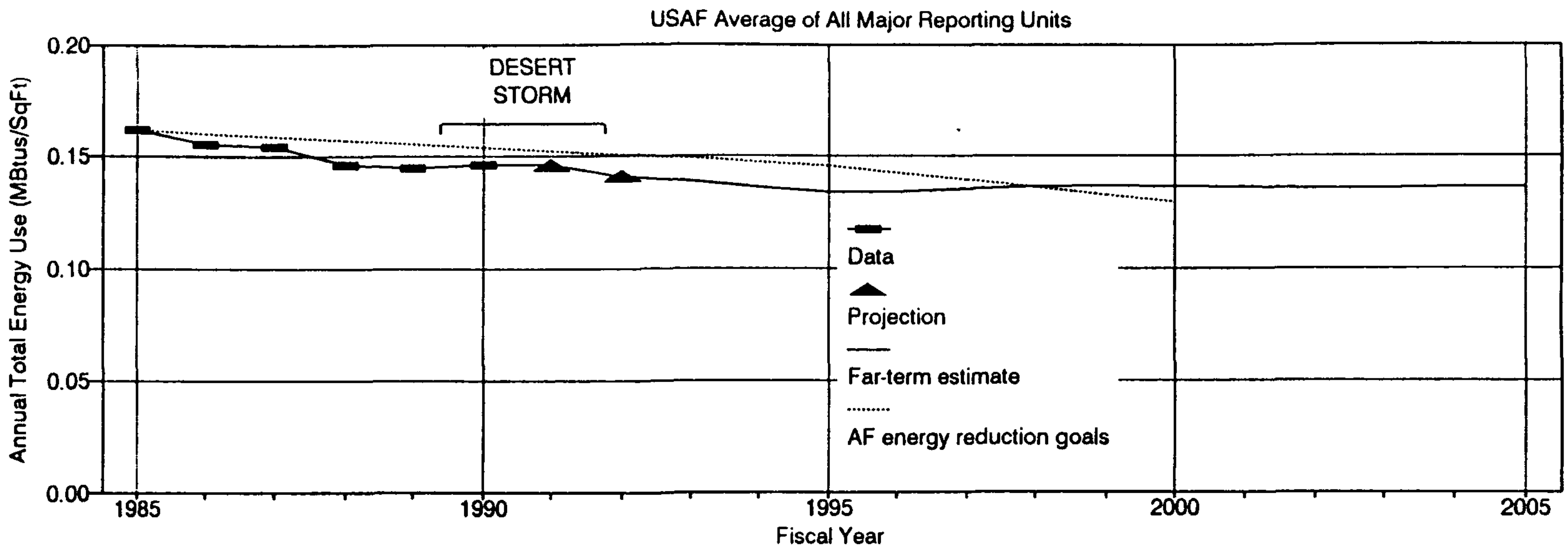


Figure 53. Projected Annual USAF Total Facilities Energy Consumption, Normalized to Floor Area, Following Potential Airbase Closures.

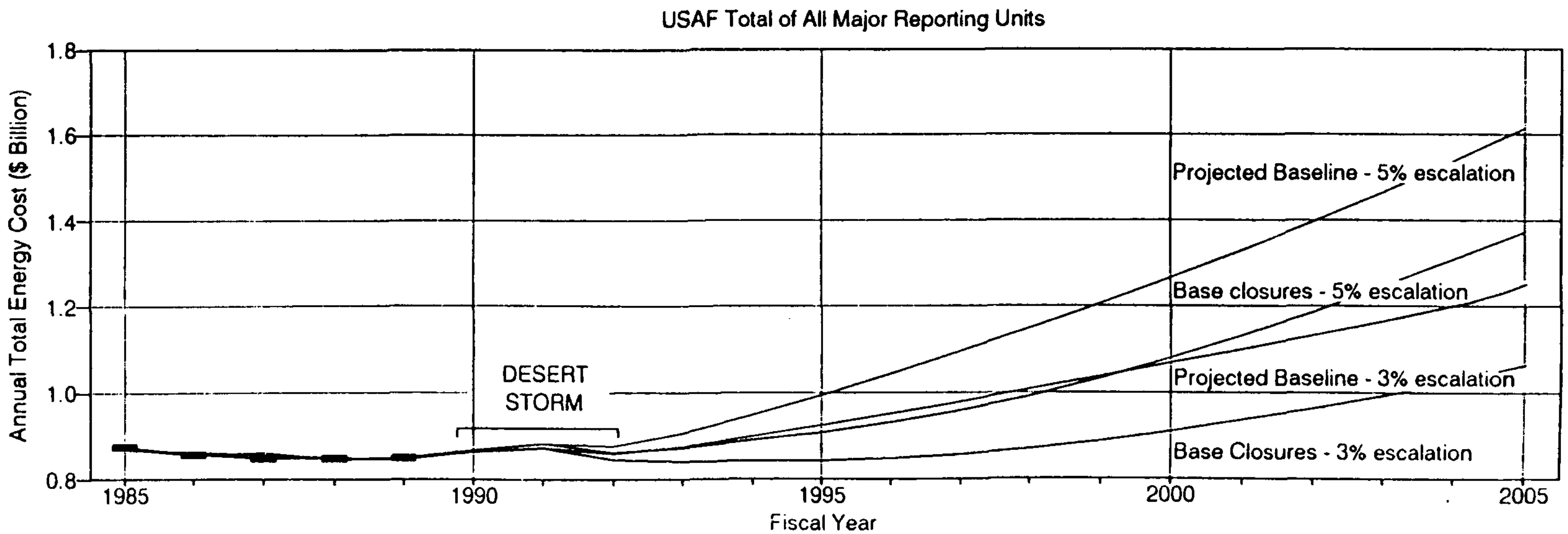


Figure 54. Projected Annual USAF Total Facilities Energy Costs Following Potential Airbase Closures.

Second, as world reserves of oil continue to decline, the competition for these fuels on the world market will increase. This worldwide competition will be significant in the mid term and become intense with the next 30 years (far term). AF competition for petroleum fuels for flying (JP-4, JP-8, etc.) versus petroleum fuels for facilities operations (fuel oils, diesel fuels) will yield to the flying component. Thus, airbase and other AF installations currently dependent upon petroleum fuels will be forced to switch to other energy sources. Beyond 50 years in the future, competition for natural gas may force similar changes on AF installations similarly dependent upon that energy product.

Third, increasing worldwide competition for all forms of energy along with increasing environmental constraints will continue to escalate energy costs across all sectors. Even with the planned reductions in force structure and base closures, airbase energy operations dependent upon conventional energy sources will continue to demand higher percentages of AF O&M funds.

Finally, as more advanced AF systems begin to emerge in the far term, a need for greater quantities of more exotic fuels, such as liquid hydrogen, will occur. The methods and sources developed for providing these fuels could have major effects on airbase energy operations and costs.

SECTION VI
EMERGING ENERGY TECHNOLOGIES

A. LITERATURE SEARCH[1]

A large number of energy-related technologies and processes are under development. To gain a full awareness and understanding of ongoing energy-related research and the many energy system technologies that are being developed, a literature search for energy-related topics was accomplished. Numerous technical reports, journals, publications, textbooks, magazine articles, and other documents were acquired and have been reviewed. An annotated bibliography of all these documents is being formulated and will be included as Volume III of this report.[2]

B. NEAR-TERM TECHNOLOGIES

1. Energy Effective Building Technologies

The loss of energy through inefficient building designs and construction accounts for a large share of all the energy wasted all over the world. More than 40 percent of total U.S. energy consumption, worth over $400 billion, goes for operations in the building sector. Half of that amount covers unnecessary losses as a result of ineffective building design, construction, and operations (Reference 51). Fortunately, much research, development, testing, and evaluation of a wide variety of energy-effective building technologies has been conducted over the past 20 years. Although a comprehensive review of all new building technologies is beyond the scope of this report, some selected items will be summarized here.

Many of the concepts that constitute energy-effective building design are also embodied in passive solar designs. The relevant published literature sources produced over the past 20 years are numerous, and it is considered a mature technology. The fundamental concepts embodied in passive solar building design are outlined below and illustrated in Figure 55.

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[1]Portions of this section have been adapted from The 1990 World Book Year Book, the annual supplement to the World Book Encyclopedia (World Book Publishing, 525 W. Monroe St., Chicago, IL 60606).

[2]To obtain copies of Volume III, contact Headquarters, Air Force Civil Engineering Support Agency (AFCESA/RACO), Tyndall AFB, FL.

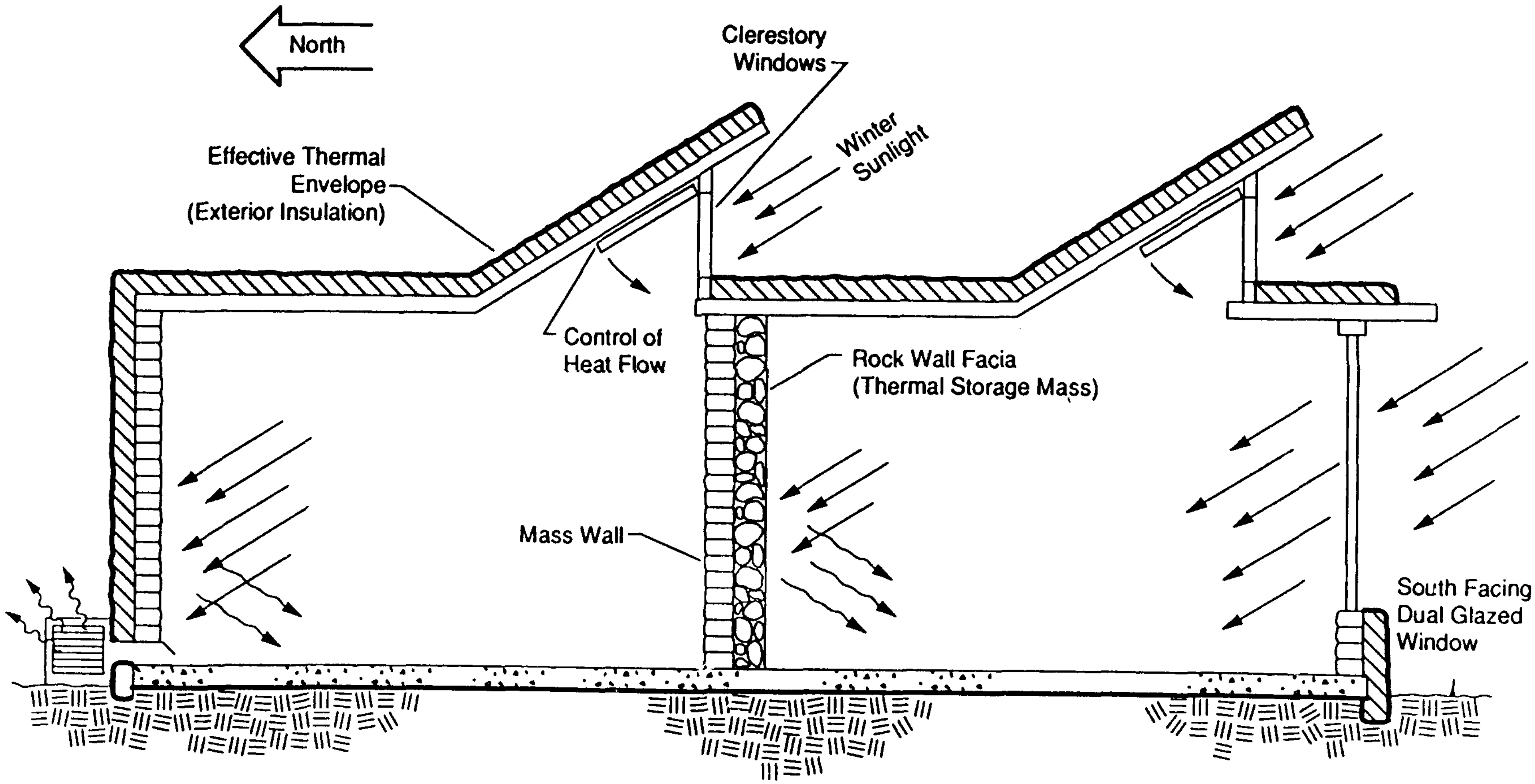

Figure 55. Passive Solar Design Concepts.

Passive solar building designs can be very cost effective in a great many regions, even those where solar insolation is not abundant at all times of the years. Initial construction costs for passive solar buildings are, however, usually somewhat higher than for conventional construction, but these costs are usually recovered in reduced energy costs early in the life of the building.

a. Orientation and Openings for Solar Gain

Successful passive solar designs require that the building be properly oriented to receive maximum exposure to the sun during the winter months (south facing) and that large areas of specially designed solar gain openings (windows, glass doors, clerestories, etc.) be included in the south-facing exposure of the building. Most textbooks on passive solar design provide design charts or rules of thumb for estimating the amount of solar gain openings required.

b. Effective Building Envelope

An effective building envelope must provide not only an adequate structural frame, it must also encompass sufficient insulation to minimize heat transport through the envelope for both heating and cooling conditions, proper sealing to prevent transfer of heat through the envelope due to air leaks, double-pane windows and doors with low-emissivity films (heat mirrors) to reduce the movement of heat through these openings during daylight hours, and properly designed insulating curtains or shutters to stop the loss of heat through windows at night. Passive solar designs usually call for greater insulation of the building envelope than conventional designs, and the insulation is usually applied to the exterior of the walls rather than the interior. Radiant barriers are often included between the wall structure and the exterior insulation. Glass foyers can be added to enclose high traffic entrances thus substantially reducing heat gain or loss.

c. Thermal Storage Mass

A key component of passive solar design is storage of the solar heat collected during daylight hours so it can be used to keep the building warm at night. Thermal storage mass is generally used for this purpose.

Any material that has a high heat storage capacity (concrete, bricks, masonry blocks, rocks, water, etc.) can be used for this purpose. Most cost-effective designs use the structural envelope as a thermal storage mass. Walls made of concrete, masonry blocks, or brick are very effective. An interior concrete or masonry block wall faced with decorative rock can be both highly attractive and effective for thermal storage.

d. Earth Berming

Berming soil against the north, east, and west walls is often an effective way to retain heat in the winter and augment cooling in the summer.

e. Ventilating Air/Heat Exchangers

Where building occupancy dictates a fresh supply of ventilating air/heat exchangers can be incorporated in the air ducts to prevent loss of heat stored in the building.

f. Building Thermal Management

Effective operation of passive solar buildings requires reasonably precise control of the curtains or shutters used to let sunlight in during the day and prevent heat loss during the night. This can be done manually or by automated control systems.

2. Lighting Systems

In recent years, there have been substantial developments in improved building lighting systems. Increased use of daylighting, especially in conjunction with passive solar designs, can be very cost effective over the life of a building. New, energy-efficient bulbs that can greatly reduce energy consumption while still providing excellent lighting have been developed and marketed (Reference 52). Multisensor activated lighting systems at locations only occasionally occupied by people can cause the lights to be turned off when no one is there. For outdoor areas, infrared motion detectors, sound detectors, radar sensors, laser beams, and vibration detectors can all be used to activate the lighting system at the onset of any activity. The lack of any signal over some period of time will cause the lights to be turned off. The same is true for building interiors where the sounds and motions of approaching people can cause hall lights to be turned on long before they arrive and turned off when activity has ceased.

3. Thermal Energy Storage Systems

a. Off-Peak Ice Generation

A very straightforward way to store energy (or in this case to store the absence of energy) is to use commercial refrigeration equipment during off-peak hours (usually nighttime hours) to make ice that is then stored in large insulated containers for use during the peak cooling period, normally during the day. The ice is stored in large, water-filled, insulated storage tanks that have coils of pipe passing through their interiors. A heat transfer fluid is pumped through the coils to transfer heat from the air handling unit to the ice bath. The refrigeration system is designed to provide refrigeration directly to the air-conditioning system when needed, although cooling in this way during peak hours can be quite expensive when electricity can cost two to three times more than during off-peak hours.

Ice storage systems have proven to be a very cost-effective way of storing cooling capacity and avoiding high, air-conditioning costs during periods of peak demand. Such an ice storage system was included in the new Hyatt Regency Hotel recently constructed in Albuquerque, NM. Ice storage systems offer great potential for substantial cost savings at many military bases (Reference 53).

b. Molten Salt Storage

A most effective method for storing high-temperature thermal energy is through the use of molten metallic salts. Mixtures of sodium nitrate and potassium nitrate, frequently used for this purpose, melt at about 224 °C (435 °F) and then can be considered a high-temperature working fluid. The fluid can be heated to temperatures as high as 649 °C (1200 °F) and stored in insulated tanks for later use. It can also be used to produce steam that in turn drives steam turbine/generators to produce electricity. Molten salt can be used to store highly concentrated solar energy to produce electricity during nighttime hours.

4. Cogeneration

Cogeneration is a term used for the simultaneous production and use of two or more energy products from a single energy source (for example, both steam and electric power produced from natural gas). There are several types, variations, and sizes of cogeneration systems, some in small pre-packaged units. A very common system is one that burns natural gas in a gas turbine which in turn runs a generator to produce electricity. The exhaust gases are passed through a boiler to produce steam for heating buildings or meeting process heating requirements. In a further extension of the process, the steam can be run through an absorption chiller to produce chilled water for air conditioning. The primary advantage of cogeneration is the conversion of more than 80 percent of the input energy to useful purposes, of which approximately 30 percent is high-valued electric power. This is in contrast to most large fossil fuel power plants where approximately 30 percent of the input energy is converted into electricity, and the remaining 70 percent is wasted into the atmosphere. Also cogeneration plants are usually located near the primary user facility, thus avoiding additional losses in electric power that occur when it must be transported over long lines.

A very successful gas-fired 2.5 MW cogeneration plant is in operation at the University of New Mexico (Albuquerque) and provides chilled water for cooling the computer center and electric power to offset part of the campus power load (Reference 54).

Development of commercially owned and operated cogeneration plants is continuing at a rapid pace. An especially successful company, Power Systems Engineering, Inc. (Beverly Hills, CA) has a number of plants on line (Table 7). Particularly successful is their 550 MW Lyondell plant in Houston, TX. Electric power produced by this cogeneration plant is wheeled through local transmission lines to the Texas Utilities grid that serves Dallas while steam from the plant is piped across the street where it is sold at a profit to the Arco Chemical Company. The Lyondell plant uses both natural gas-fired turbines and a waste heat-powered steam turbine to achieve an unusually high (approximately 50 percent) conversion of input energy to electric power. More detailed information on the UNM cogeneration system is provided in Appendix D.

a. Cost Benefits

To determine the potential cost benefits that cogeneration systems might provide over conventional power systems at various ratios ($R_{t/e}$) of thermal load (L_t) to electrical load (L_e), several cases were calculated (Figures 56 through 59). A small computer program that modeled the performance and associated costs of both conventional and cogeneration power systems was developed. The ratio of airbase thermal and electrical energy loads ($R_{t/e}$) varies from one to two. These air base energy loads were derived using commercial electrical power and an onbase steam plant in the upper half of each diagram and commercial electric power and onbase cogeneration in the lower half of the diagram. Both the overall cost of energy for the airbase and

TABLE 7. PROJECTS COMPLETED AND OPERATED BY POWER SYSTEMS ENGINEERING, INC.[a]

Project	Operation	Cost (million)	Power (MW)	Steam Output (lbs/hr)
Chalk Cliff	1990	$49	46	55,000
San Juaquin	1990	57	48	45,000
Kern Front	1989	49	48	110,000
High Sierra	1989	49	48	110,000
Double "C"	1989	49	48	110,000
Corona Energy	1988	43	46	37,000
Cogen Lyondell	1985	217	465	1,150,000
Cogen Power	1983	60	5	550,000
			754	2,167,000
11 Projects for others	1970-1988	186	470	3,400,000
			1,224	5,567,000

[a]Abstracted from Reference 55.

the average cost/unit of energy ($/MBtu) are calculated for each case. Only operational costs are included in these comparisons, not capital costs.

In Figure 56, the total airbase load is 200 MBtus, and the ratio of thermal to electrical is 1. Total energy costs for the conventional approach is $2300; average energy cost is $11.50/MBtu. For the same case using cogeneration the total energy cost is $1759 and the average cost is $8.80/MBtu. In Figure 57, the ratio ($R_{t/e}$) remains the same but the airbase load is increased to 300 MBtus. While the overall energy costs have risen ($3450 for conventional vs. $2643 for cogeneration), the average cost values have remained the same as in Figure 56 showing that the analysis holds for various levels of air base consumption, all else being constant.

In Figure 58, $R_{t/e}$ has been increased to 1.75 with all else the same as in Figure 57. While the overall costs are different ($2917 for conventional vs. $1882 for cogeneration), an even greater difference is noted in the average cost values ($9.72/MBtu for

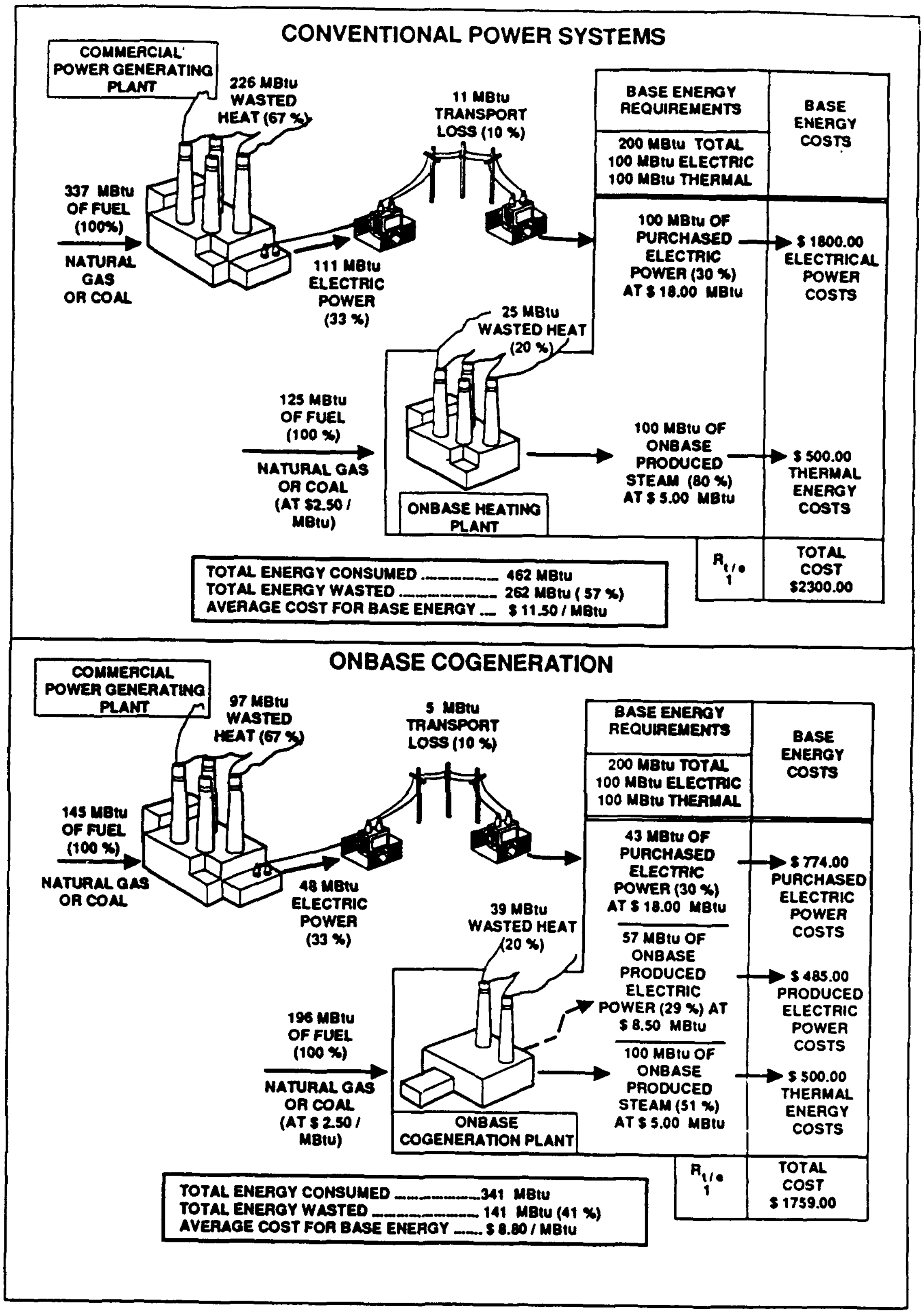

Figure 56. Energy Costs for Cogeneration vs. Conventional Power Systems (Load=200 MBtu, $R_{t/e}$=1).

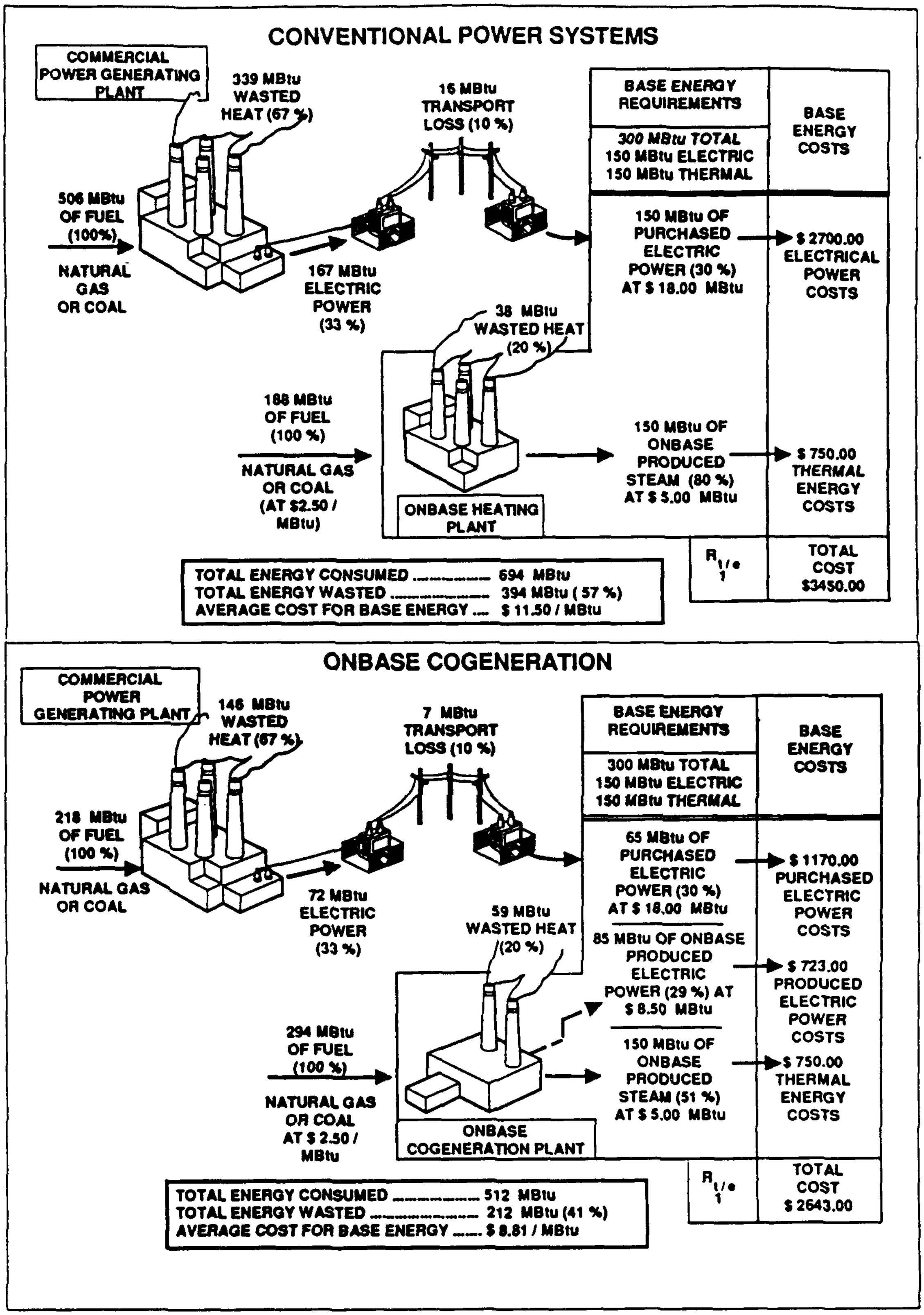

Figure 57. Energy Costs for Cogeneration vs. Conventional Power Systems (Load=300 MBtu, $R_{t/e}$=1).

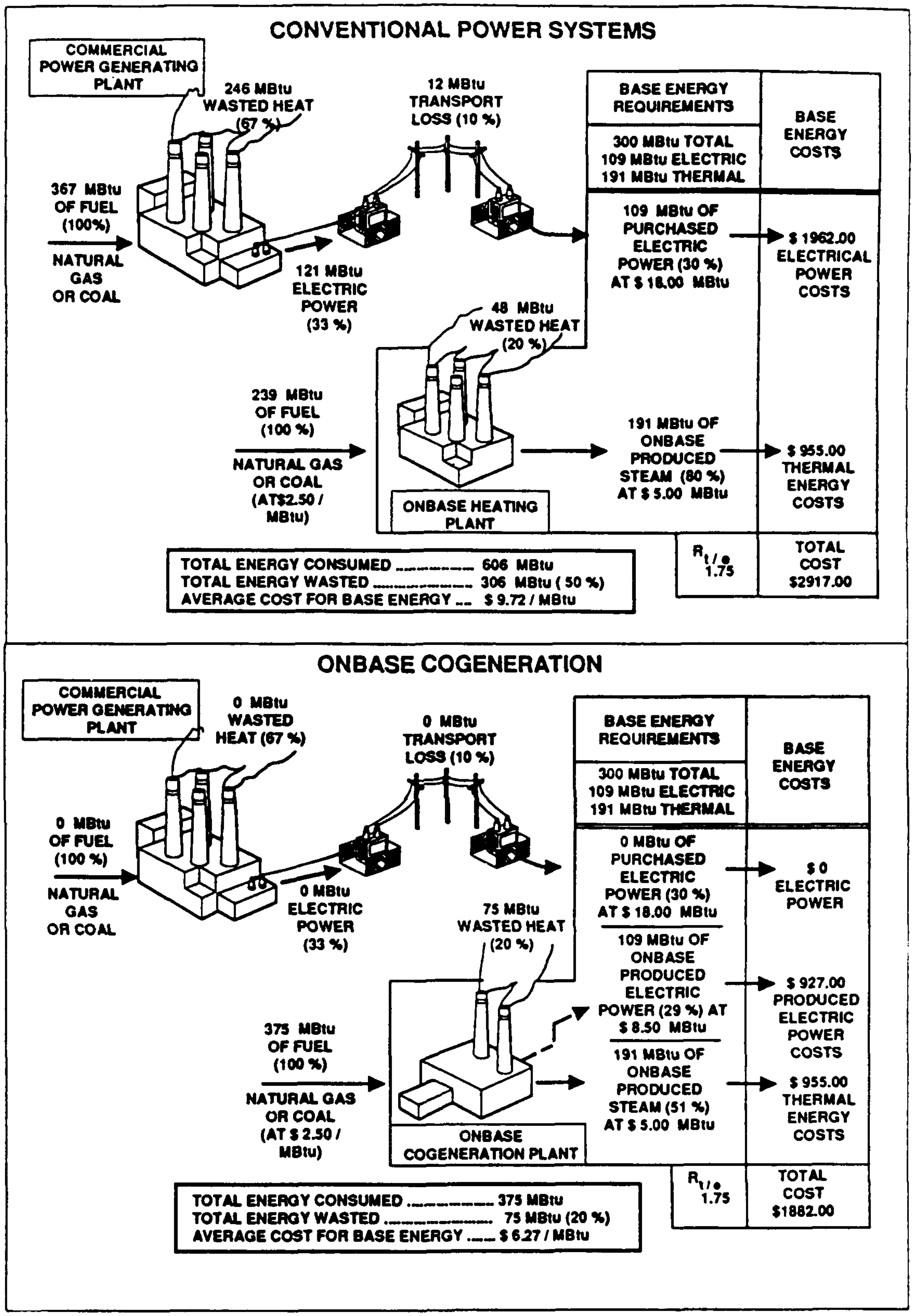

Figure 58. Energy Costs for Cogeneration vs. Conventional Power Systems (Load=300 MBtu, $R_{t/e}$=1.75).

conventional vs. \$6.27/MBtu for cogeneration). In Figure 59, $R_{t/e}$ is increased to two and the difference in average energy costs (\$9.33/MBtu for conventional vs. \$6.14/MBtu for cogeneration) is slightly less, indicating the maximum cost benefit to occur at $R_{t/e}$ near 1.76. Notice also the substantial reduction in energy wasted with cogeneration as compared to the conventional approach (Figures 56 through 59). To show the cost benefits to be achieved through cogeneration the differences in the average cost of energy (\$/MBtu) between conventional and cogeneration are plotted versus $R_{t/e}$ (Figure 60). The cost of purchased electricity is assumed to be \$18/MBtu, the sell-back price (to the utility) is \$9/MBtu, the cost to produce onbase steam is assumed to be \$5.00/MBtu, and the cost of cogeneration produced electricity is \$8.50/MBtu. The maximum cost benefit occurs at $R_{t/e} = 1.76$ and, for this case, amounts to a cost saving of \$3.44/MBtu for all of the energy consumed on the airbase. It is also obvious that significant cost savings can be achieved with cogeneration when $R_{t/e} = 0.5$ continuing through $R_{t/e} = 2.0$ with maximum benefits around $R_{t/e} = 1.76$.

In Figure 61, the cost of commercial power has been assumed to be \$20/MBtu and the sell-back price is \$10/MBtu. All else is the same as for Figure 60. The maximum cost benefit is approximately \$4/MBtu at $R_{t/e} = 1.76$. In Figure 62, the cost of commercial power is assumed to be \$25/MBtu with sell-back price at \$12.50/MBtu. The maximum cost benefit is \$5.98/MBtu at $R_{t/e} = 1.76$. The overall variation of cost benefit with cost of commercial electricity is shown in Figure 63 where the maximum cost benefit has been plotted versus the cost of commercial electricity. $R_{t/e}$ is held at 1.76 and no sell-back of electricity to the utility occurs. Maximum cost benefits range from zero at about \$8.50/MBtu for commercial power to nearly \$12/MBtu when commercial power is \$40/MBtu.

Estimated energy conversion efficiencies (fuel energy to electricity) for gas turbine cogeneration systems of different sizes are shown in Figure 64. The estimated costs of gas turbine cogeneration systems (in 1989) are shown as a function of system size in Figure 65. In conclusion, there are many cases where substantial reductions in energy consumption and associated costs can be achieved through the use of onbase cogeneration systems.

b. System Constraints

Several constraints dictate the applicability and cost-effectiveness of cogeneration. First, there must be a practical use for and a cost benefit associated with the use of the thermal energy produced by the cogeneration plant. For example, it might displace and thus avoid the cost of other fuels used for heating buildings or meeting other heating requirements.

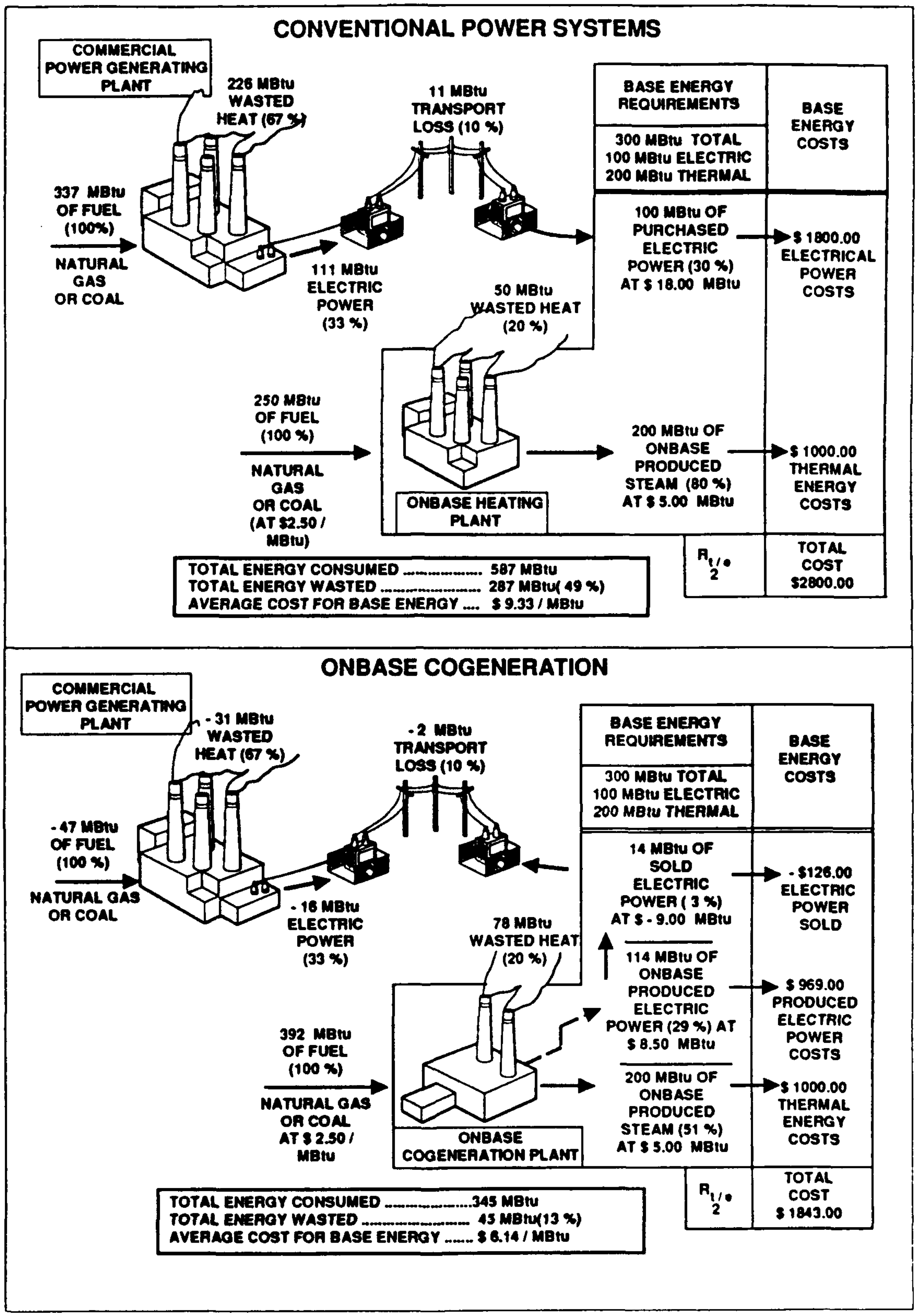

Figure 59. Energy Costs for Cogeneration vs.Conventional Power Systems (Load=300 MBtu, $R_{t/e}$=2).

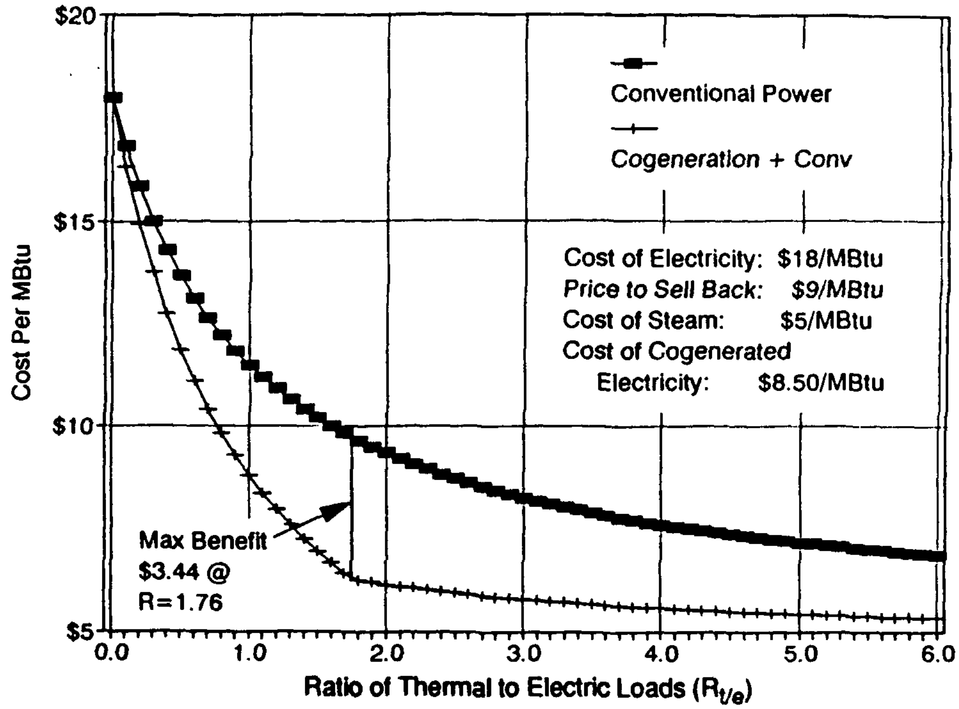

Figure 60. Cost Benefit vs. Thermal/Electric Ratio, Cogeneration vs. Conventional (Cost of Commercial Electricity = $18/MBtu).

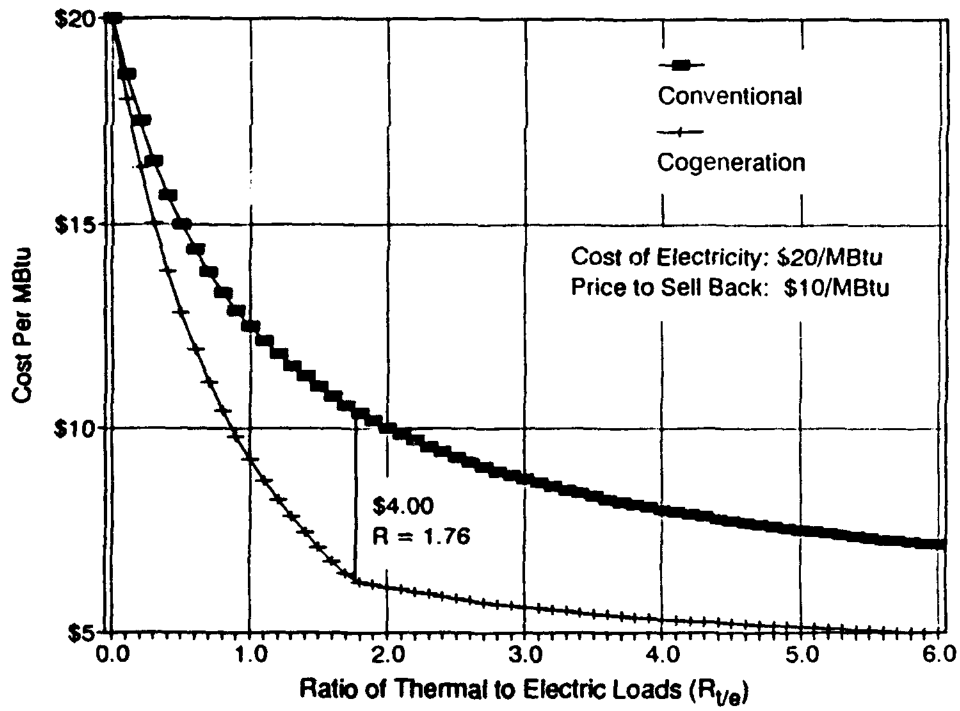

Figure 61. Cost Benefit vs. Thermal/Electric Ratio, Cogeneration vs. Conventional (Cost of Commercial Electricity = $20/MBtu).

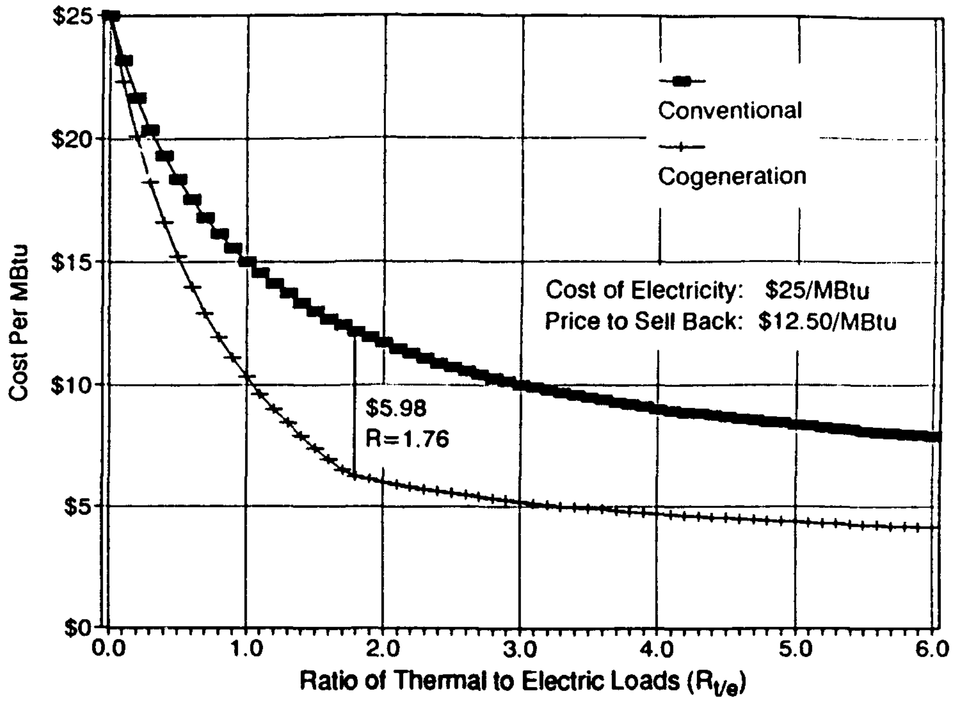

Figure 62. Cost Benefit vs. Thermal/Electric Ratio, Cogeneration vs. Conventional (Cost of Commercial Electricity = $25/month).

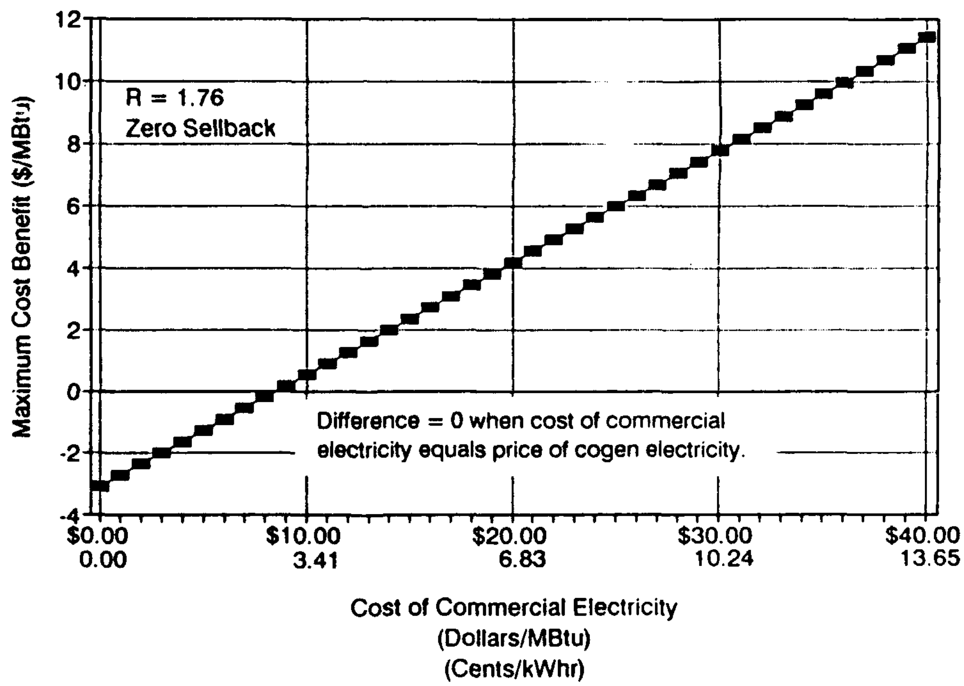

Figure 63. Maximum Cost Benefit (Conventional Minus Cogeneration) vs. Cost of Commercial Electricity.

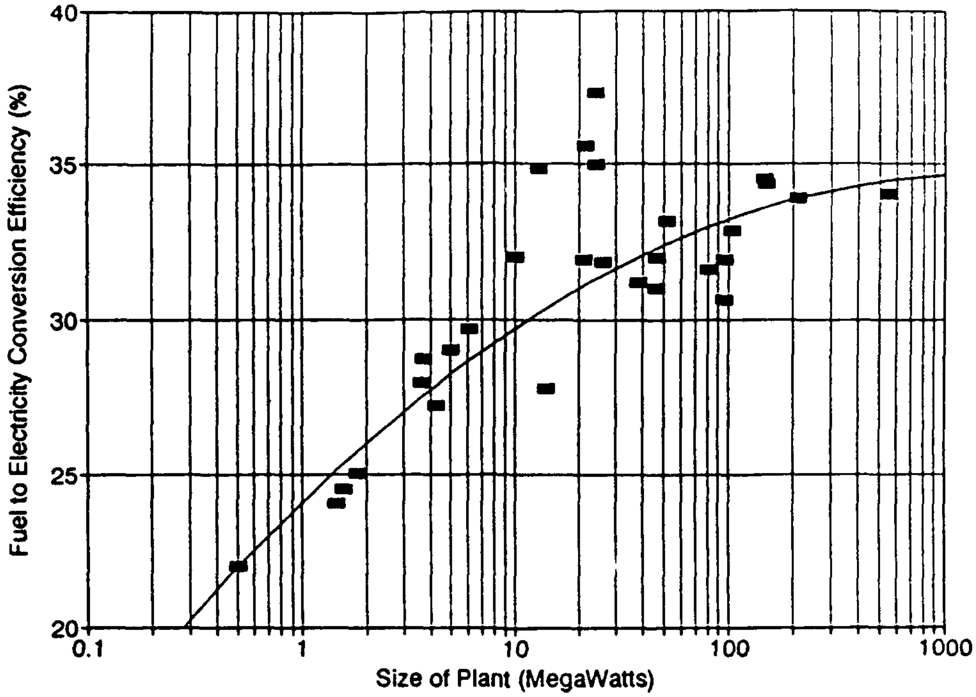

Figure 64. Energy Conversion Efficiencies (Fuel to Electricity) for Various Sized Gas-Turbine Cogeneration Systems.

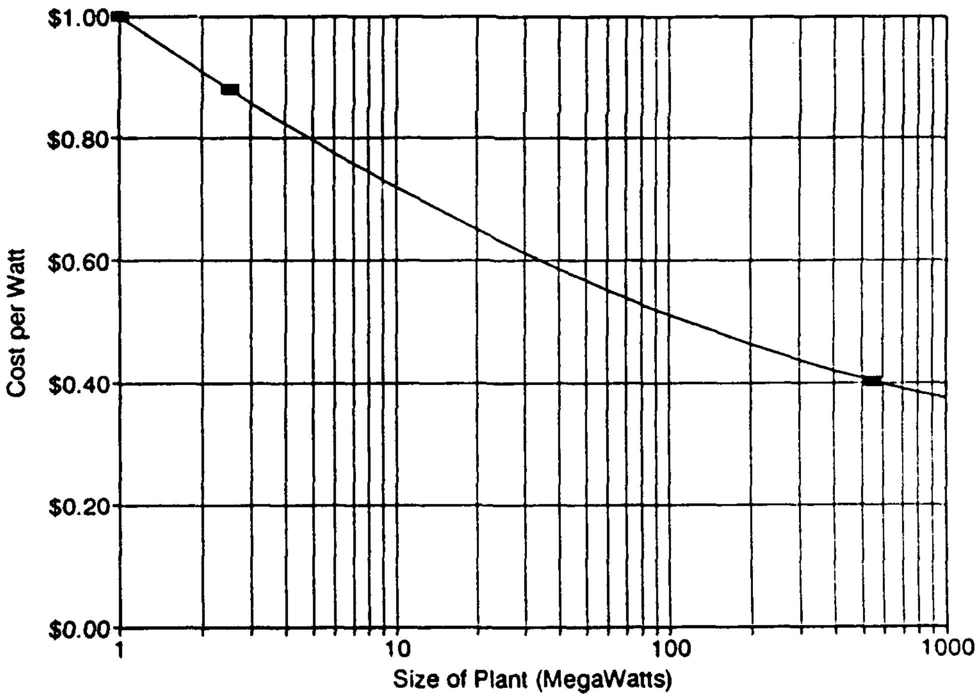

Figure 65. Estimated Capital Costs for Gas-Turbine Cogeneration Plants vs. Size of Plants.

Second, the use of the heat from the cogeneration plant often requires a supporting infrastructure such as a central steam distribution system. Third, as shown in the calculations above, the thermal energy load must be substantially greater than the electrical power load over most of the year for maximum cost effectiveness because cogeneration plants produce more thermal energy than electrical power. Finally, the cogeneration plant should be located close to the place of use, since the transfer of thermal energy over long distances is not cost effective.

5. Absorption Cooling

Great progress has been achieved in recent years in the field of absorption cooling. In general, lithium bromide (LiBr) cooling technology has been developed into reliable systems that have largely replaced older and less reliable ammonia-based absorption systems. These new systems work on the basic principle that as water is absorbed into a concentrated solution of LiBr the temperature of the resulting diluted solution is substantially lowered and can be used to chill water for air conditioning. Heat can then be used to boil the dilute solution, thus separating the water and reconcentrating the LiBr.

a. Large Absorption Cooling Systems

A typical large LiBr absorption chiller system is depicted in Figure 66. It consists of a large tank that is pumped down and held at a partial vacuum. A concentrated solution of LiBr, stored in a reservoir near the top of the system, and water, stored in a separate reservoir near the top of the system, are spray-mixed together at the top of the middle chamber, substantially lowering the temperature of the combined dilute solution. The cold solution then flows down over the water-filled tubes of a conventional heat exchanger to produce chilled water. The dilute LiBr solution settles in the bottom of the system where it is pumped back to the reservoir near the top of the system. Steam from an external source is passed through a heat exchanger in the LiBr reservoir to boil off water vapor and reconcentrate the LiBr solution. Boiling of the water occurs at a much lower temperature because of the partial vacuum. The evaporated water moves by vapor pressure across a partition into a separate chamber where water from an external cooling tower is passed through cooling coils to condense the water vapor back to liquid and further cool this water. The recovered water is again spray-mixed with the reconcentrated LiBr to begin the cooling process over again. The system works entirely on heat energy (uses steam to produce chilled water) requiring only small amounts of electrical power for pumping. Thus, LiBr absorption systems are ideally suited for use with steam produced by either natural gas or coal-fired boilers or with cogeneration systems or other sources of waste heat. They use no CFC refrigerants and are

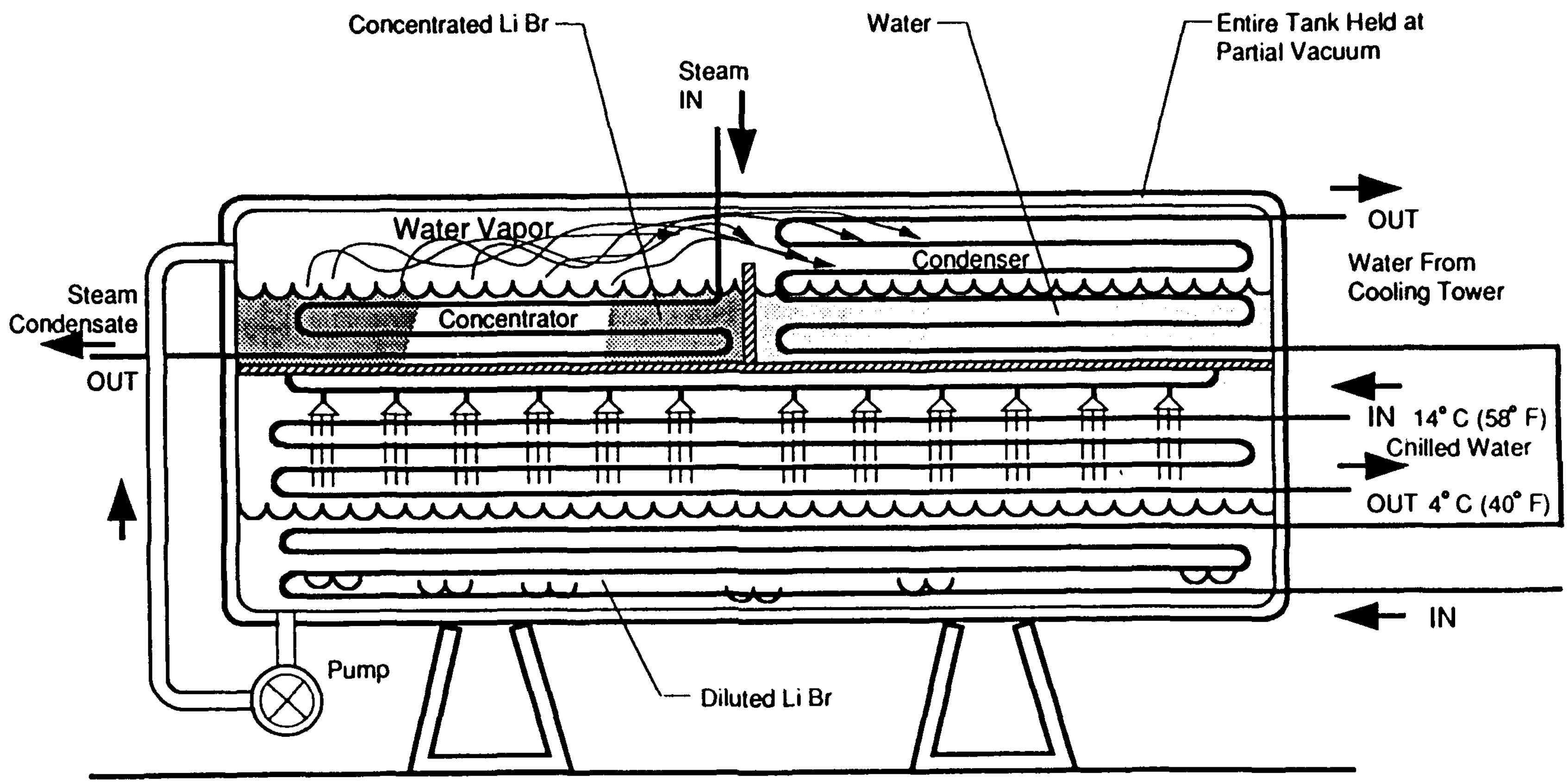

Figure 66. Large LiBr Absorption Chiller System.

thus more environmentally compatible than mechanically-driven refrigerated chiller systems. The waste heat coming to the cooling tower from the absorption chiller can instead be used to heat domestic hot water, thus saving additional energy and costs. LiBr absorption chiller systems, in general, have lower capital costs and are less expensive to operate than comparable vapor compression refrigeration systems. These systems are reliable and require very little maintenance or attention during operation.

b. Small Absorption Cooling Systems

The LiBr absorption cooling technology described above is now being developed for smaller systems suitable for single family residences or small office buildings (Reference 42, p. 59). A small company in Arizona is developing a system that operates entirely at ambient pressure (no vacuum) and uses a combination of LiBr liquid desiccant in one part of the system and a water spray in another part to cool the outside air from 35 to 27 °C (95 to 80 °F) and produce 50 percent relative humidity. The exhaust air, returning from the cooled building passes through another part of the system where additional water is sprayed to further cool the air stream, which, in turn, is used to further extract heat from the first part of the system. A small, natural gas-fired boiler is built into the system to boil the water out of the diluted LiBr solution, reconcentrating it to continue the process. The system uses electricity only for moving air and pumping water and LiBr solutions. The *entire* process requires less than half the amount of electrical power as a vapor-phase refrigeration air-conditioner of equal capacity and is expected to cost only half as much to operate. The capital cost for this system is also expected to be less than refrigerated systems of equal capacity once mass production is achieved.

A second small, liquid desiccant system has been developed by another company for the purpose of making ice with sunlight (Reference 56). Called ISAAC (Intermittent Solar Ammonia Absorption Cycle), the system uses liquid ammonia as the desiccant (Reference 42, p. 59) and operates on an intermittent cycle. During daylight hours heat from a parabolic trough solar collector is used to boil the water out of the liquid desiccant solution thus reconcentrating the ammonia. No ice is produced during daytime hours. At sunset a valve is reset, and the liquid desiccant is mixed with water to produce a very cold solution used to freeze water in the ice-making compartment, where the process continues throughout the night. In the morning the ice is removed, new water is added, and the valve reset for the solar-heated desiccant concentrating process to resume. Current prototype machines can produce 80 pounds of ice in 24 hours.

6. Geothermal Systems

Geothermal energy, a seemingly inexhaustible source of renewable energy, is rapidly being recognized as a potential major contributor to the world's energy needs. This source of thermal energy, discovered at numerous locations all over the world, at depths ranging from near the surface to many thousands of feet, is thought to result from the constant shifting of the tectonic plates of the earth's crust and the formation of pockets of high pressure and heat. Long-term radioactive decay of elements deep in the ground is also thought to contribute heat energy. Several forms of geothermal energy are known to exist: pools of hot water 149 °C (≈300 °F), pressurized vents of hot water and steam, regions of hot dry rocks that can be used to make steam from injected water, etc.

A variety of systems are available for capturing geothermal energy and converting it into useful power. Most use geothermal-produced steam to drive a steam turbine/generator. Some use the artesian flow of pressurized steam directly from the ground to operate the turbine, while others use the subsurface hot water or hot dry rocks to produce steam from injected water. In many systems water is preserved and reinjected into the ground. A more modern approach employs a binary system where the hot water or steam from the geothermal well is passed through a heat exchanger to vaporize a secondary working fluid that operates the turbine. The cooled geothermal water is reinjected into the ground. *Such binary cycle systems provide a cleaner* working fluid to operate the turbine thus reducing maintenance and repair costs and greatly extending the life of the system. The waste heat from geothermal power systems (hot water at 85 °C [≈185 °F]) can be effectively used for a variety of purposes (heating homes, buildings, greenhouses, fish farms, etc.) thus further increasing the cost benefits of this energy source.

Geothermal power, currently a multibillion dollar industry in the US, is growing rapidly with 2300 MW of power currently on line. There are 178,000 MW of geothermal power identified and awaiting development in the US today.[1] It is perhaps the cleanest and least obtrusive form of renewable energy known. A major geothermal power system can occupy less than an acre of land and does not require damming a major river or erecting wind turbines over hundreds of acres of land. The state of Nevada has gone from no geothermal power systems to 120 MW in less than three years. Several cities have either decided to install geothermal power systems or have agreed to use the waste hot water from such systems to heat city buildings (district heating).

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[1]Personal communication, Steve Munson, Vulcan Power Co., Franktown, CO, May 1991.

Geothermal power is a very rapidly maturing industry. Its only drawback, similar to wind, is that it is only available where the resource is discovered.

7. Solar Thermal Systems

The use of sunlight to produce heat is an ancient concept that has evolved to a mature technology over the past 20 years. Numerous solar collector systems were developed and tested during the 1970s, and many continued into production systems during the 1980s. Federal and state solar tax credits available during that period greatly encouraged the industry.

Solar thermal systems require relatively large areas for installation and a fair amount of cleaning, maintenance, and upkeep to provide maximum performance. These systems can be used to produce heated air, hot water, steam, or to heat thermal transfer fluids. Temperatures ranging from 38 to 399 °C (100 to 750 °F) can be obtained with different systems. Flat-plate solar collectors (Figure 67) are the most common and least expensive. Although many different types and models are available, they normally consist of a black collector plate over which air is passed and heated (hot air type) or one to which tubes are attached for the heating of water (hot water type). The collector plate is enclosed in an insulated frame with a double-glazed glass cover to let in the sunlight. Flat-plate collectors can produce heated air in the low-temperature ranges, 38 to 66 °C (100 to 150 °F), for space heating or hot water up to 93 °C (200 °F) for domestic purposes. Flat-plate collectors are normally attached permanently at a fixed angle to roofs of buildings or to frames mounted on the ground, although some can be seasonally adjusted for optimum performance.

Concentrating solar collectors are used when higher temperature fluids are required. Parabolic trough collectors are the most common with some dish type concentrator used for the highest temperatures. Parabolic trough collectors consist of a reflective surface curved in the shape of a parabola (Figure 68). This surface is usually of mirrored glass or sheet metal covered with a reflective plastic. Sunlight shining on the parabolic trough is reflected onto a collector tube located at the focus of the parabola. The collector tube is a metal pipe coated with special black materials to increase heat absorption. It is often placed inside a glass outer tube, and a vacuum is created between the tubes to reduce convective heat loss from the collector tube. Throughout the day parabolic trough collectors must be continuously tilted at the optimum angle (single-axis tracking) to obtain maximum performance. Working fluid temperatures as high as 399 °C (750 °F) or steam can be obtained from these systems.

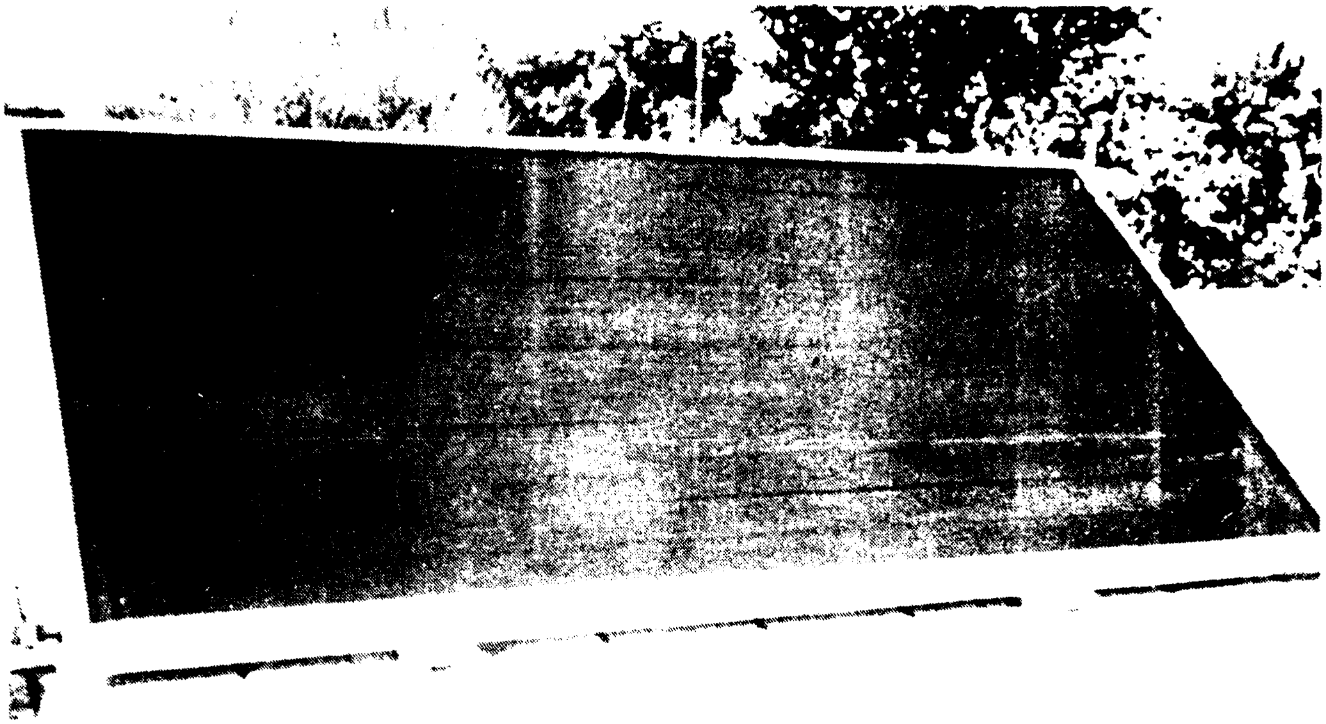


Figure 67. Flat-Plate Solar Collectcrs.

Figure 68. Single-Axis Tacking, Parabolic Trough Solar Collectors.

Dual-axis tracking parabolic dish collectors (Figure 69) are used only for very high temperature working fluids or the production of steam. They are considerably more expensive than trough collectors and thus are less frequently used.

Solar thermal systems can be used effectively to reduce consumption of fossil fuels and associated costs in a great variety of applications. Flat-plate collectors are widely used on homes and office buildings for domestic hot water. Parabolic trough systems can be used to provide process steam for a variety of industrial applications. Solar produced steam can also be used to operate LiBr absorption chillers, thus parabolic trough collectors can be used for both heating and cooling large buildings or industrial complexes. Parabolic dish solar thermal systems can be used for industrial process heat where even higher temperatures are required.

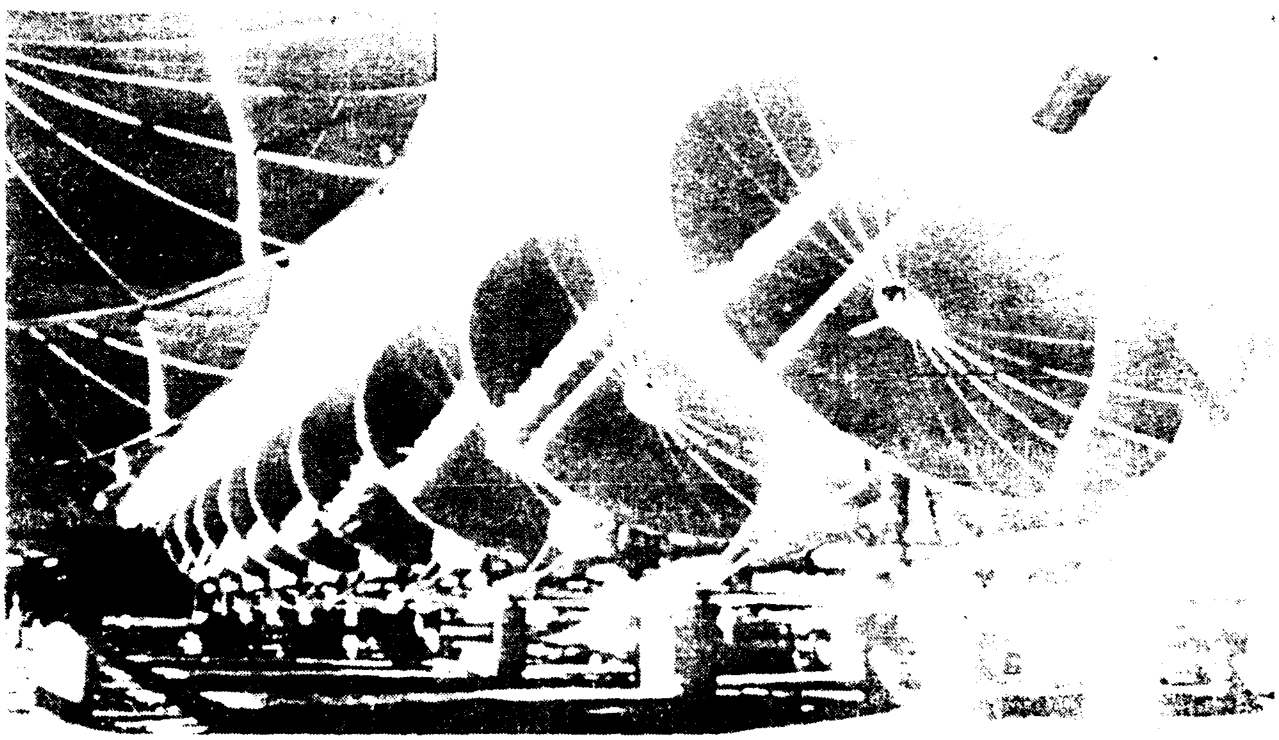


Figure 69. Dual-Axis Tracking, Parabolic Dish Concentrating Solar Collectors.

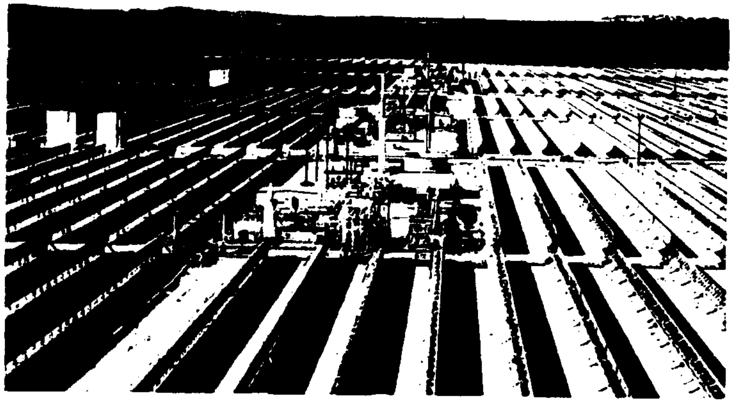
8. Solar Thermal Electric Systems

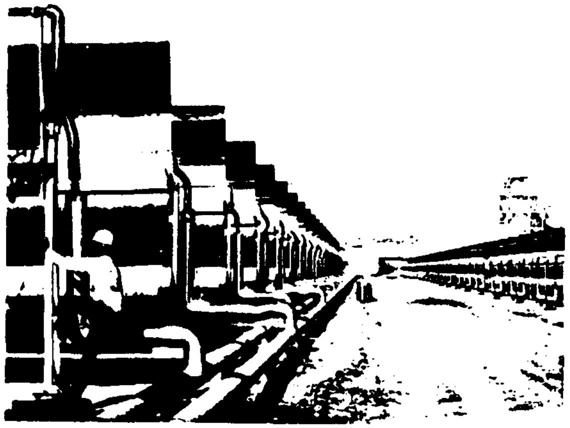
Solar thermal electric systems, in general, use sunlight to produce a hot working fluid, which produces steam to run a steam turbine and electric generator. At least one major company has emerged in the last 10 years that uses solar thermal energy to produce large quantities of electric power. Luz, International, a California corporation, uses large fields of trough solar collectors to produce steam and drive turbines to generate electric power (Figure 70). The solar field is composed of parabolic trough solar collectors that individually track the sun using sun sensors and microprocessors. The collectors focus sunlight onto specially coated steel pipes mounted inside vacuum-insulated glass tubes. The pipes contain a heat transfer fluid, which is heated to approximately 391 °C (735 °F) and pumped through a series of conventional heat exchangers to generate superheated steam. The steam powers turbine/generators to produce electricity that is delivered to the utility's electric grid.

To ensure uninterrupted power during peak demand periods, an auxiliary boiler, fueled by natural gas, is available as a supplemental source of heat. A central computer system monitors and controls each of the hundreds of individual solar collectors in the field as well as the heat transfer fluid system. Luz has constructed and operates eight major plants with a combined capacity of 470 MW. Additional plant construction, now under way, will increase Luz's capacity to over 670 MW by 1994.

A second type of solar thermal electric system is the Central Solar Receiver (CSR) power system where a field of dual-axis tracking heliostats is placed around a central tower (Figure 71). The heliostats are concentrating solar reflectors, each with the correct parabolic curvature to focus the sunlight onto a boiler located at the top of the central tower. A computer controlled tracking system keeps each individual heliostat properly oriented so that its reflected sunlight becomes a focused, high-temperature spot on the boiler. A 100 MW CSR power system would use well over 5000 of these sunlight focusing heliostats, each as large as 1300 ft^2.

The boiler on top of the tower captures the heat focused on it by the heliostat field and transfers it to a working fluid. The working fluid is then used to make steam, which operates a conventional steam turbine/generator to produce electricity. During early development of CSR technology, water was used as the working fluid to produce steam directly at the boiler. Many difficulties were encountered with the approach, especially since the entire piping system, even to the top of the tower, had to operate at the pressure of the produced steam. Also, it was not feasible to store steam for producing electricity during the night. Over the last several years CSR systems





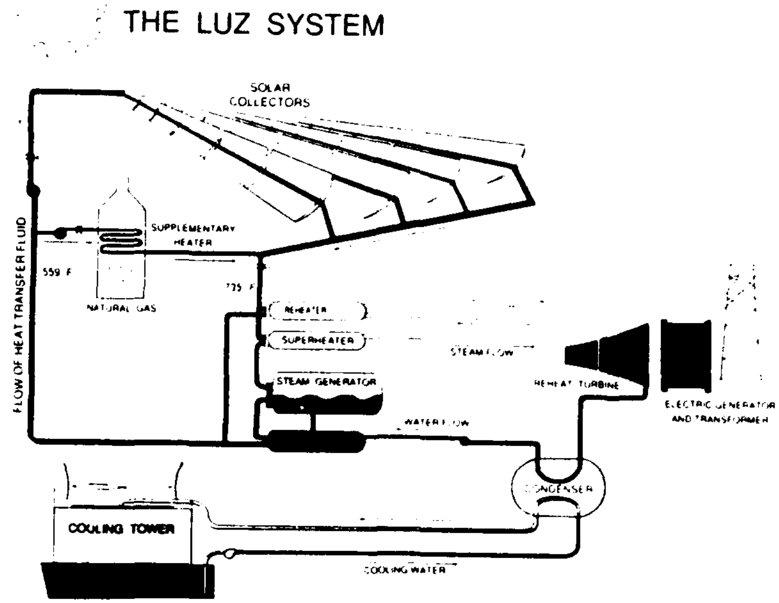


Figure 70. Solar Thermal Electric Generating Plant.

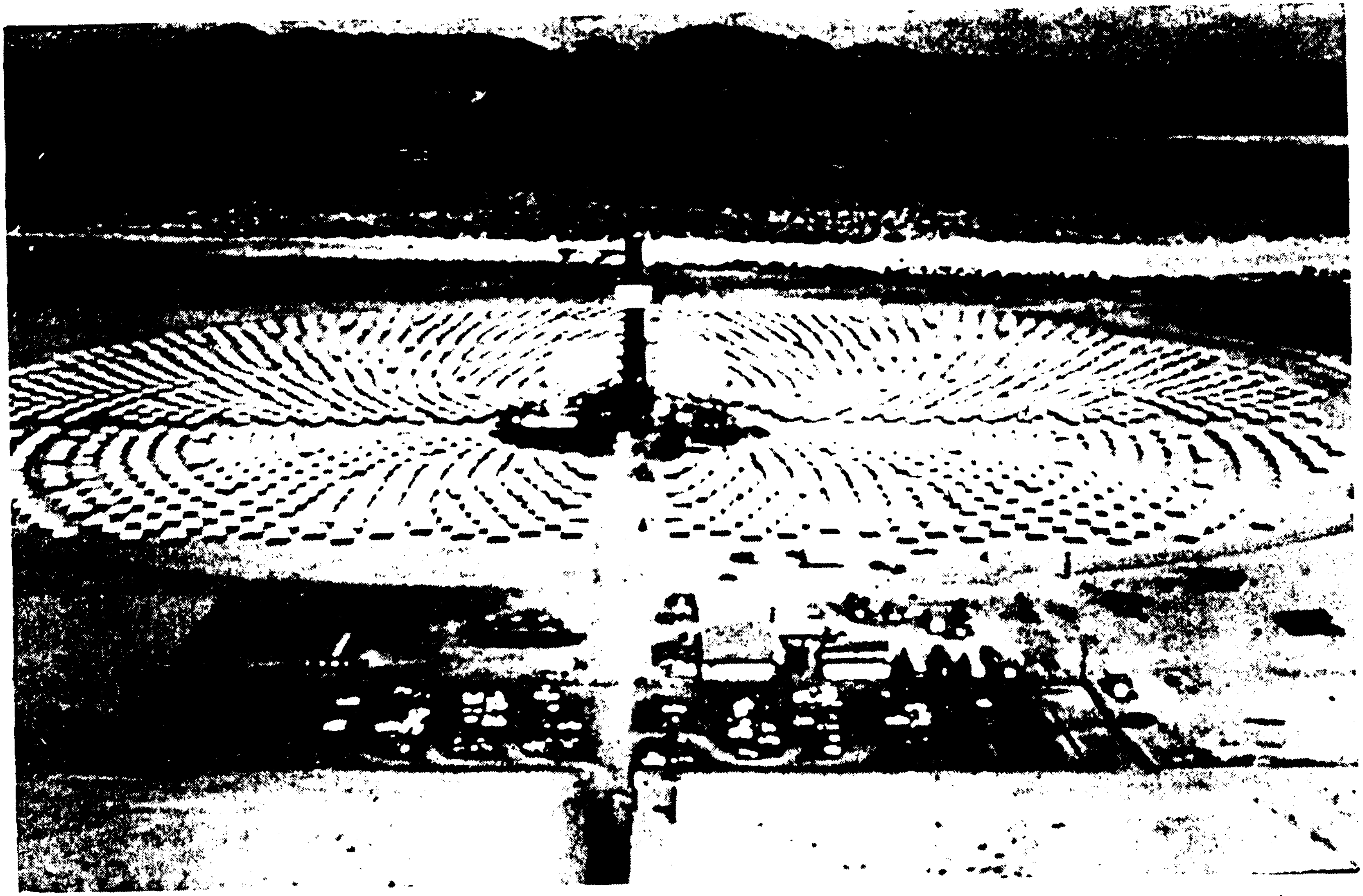


Figure 71. Central Solar Receiver System.

that use molten salts as the working fluid have been developed. As explained earlier, molten salts, such as sodium nitrate/potassium nitrate, melt at about 224 °C (435 °F) and remain a liquid well beyond 649 °C (1200 °F). These molten salts are not corrosive and pose much less threat of damage should a broken pipe occur because they solidify very quickly. The molten salt is stored in a large, insulated tank at the base of the tower. It is pumped through a heat exchanger/boiler to heat water to steam which then runs the steam turbine to produce electricity.

The unique CSR power systems are the only solar systems capable of producing very high temperatures, approximately 2760 °C (5000 °F), and thus of using molten salt as a working fluid, which then permits high-temperature thermal energy to be easily stored for power generation when the sun is not shining. This is a most important feature when considering the future of solar-powered electrical generating systems. For long periods of cloudy weather, standard, fossil-fueled boilers can be incorporated for backup.

To be cost competitive, CSR power plants must be locat^d in regions with large amounts of direct (focusable) solar insolation. They require large land areas, perhaps 800 acres for a 100 MW plant, as well as substantial O&M support to keep the many heliostats clean and properly focused. These costs can be offset by the lack of fuel costs (except during long periods of cloudy weather).

A 10 MW CSR demonstration system was constructed by the DOE near Barstow, CA (Solar One) and operated for several years by Southern California Edison, a major electric utility company. A number of difficulties were encountered since water was used as the working fluid. It was also learned that as many personnel were required for operation and maintenance (O&M) of this small plant as would be needed for a plant many times larger. Because of the high O&M costs the plant was shut down after several years of operation. DOE is now considering proposals for converting Solar One to a molten salt system and putting it back in operation.

Because of the extensive research, both experimental and theoretical, performed by Sandia National Laboratory over the past 18 years, and the operating experience gained from Solar One, CSR technology is considered to be reasonably mature. DOE is seeking opportunities to team with private industries and public utilities to construct and operate a much larger (perhaps 100 MW) CSR electric power plant.

9. Solar Thermal Electric Cogeneration

The steam turbine portions of solar thermal electric systems use conventional steam turbine technology and as such are easily adapted to provide thermal energy from the turbine exhaust for useful applications. Steam leaving the turbine can be used to operate absorption chillers to produce both chilled water for cooling and hot water and space heating for domestic purposes. If this use of thermal energy displaces thermal energy from other sources (e.g., purchased natural gas), it can make the entire process more cost-effective. Yet, the generating capacities of solar thermal electric systems, which are dictated by the size of the steam turbines, are, in general, too large for the energy needs of many military bases. Thus, as in the case of the geothermal systems described above, it would be necessary to be able to sell the excess power at a profit to other users, a factor that could limit the suitability of these systems to a few bases.

10. Wind Power

Considerable progress has been made in wind turbine technology and wind farming over the past 10 years. Several large wind power producers are now operating very successfully in California and other parts of the country. Sea West Industries and U.S. Windpower, two of the largest, are each operating several thousand large turbines (50-100 kW range), most of which are located in California (Figure 72). Flow Wind, another California company operates over 500 vertical-axis wind turbines in that state. The power produced is sold to the several California utility companies and appears to be profitable for both parties (Reference 57). The reliability of large wind turbines has improved greatly over the past 10 years, and the availability of wind-produced power is greater at most sites than was earlier predicted. Additional information regarding wind-generated electric power, extracted from a variety of sources, is provided in Appendix F.

Two new, advanced-design wind turbines are being developed. A consortium headed by U.S. Windpower is working on a variable speed, 300-kW, horizontal axis turbine, which should become available in the next five years. Sandia National Laboratories (SNL, Albuquerque, NM) has successfully completed the first year's testing of their large (150-foot high) vertical-axis research turbine (Figure 73). Located near Amarillo, TX, this variable speed machine produces 600 kW of electric power in a 30-mph wind. The operating characteristics of this machine are

Figure 72. Wind Farms in California. (Reprinted with permission from "Excellent Forecast for Wind," EPRI Journal, June 1990, p. 18.)

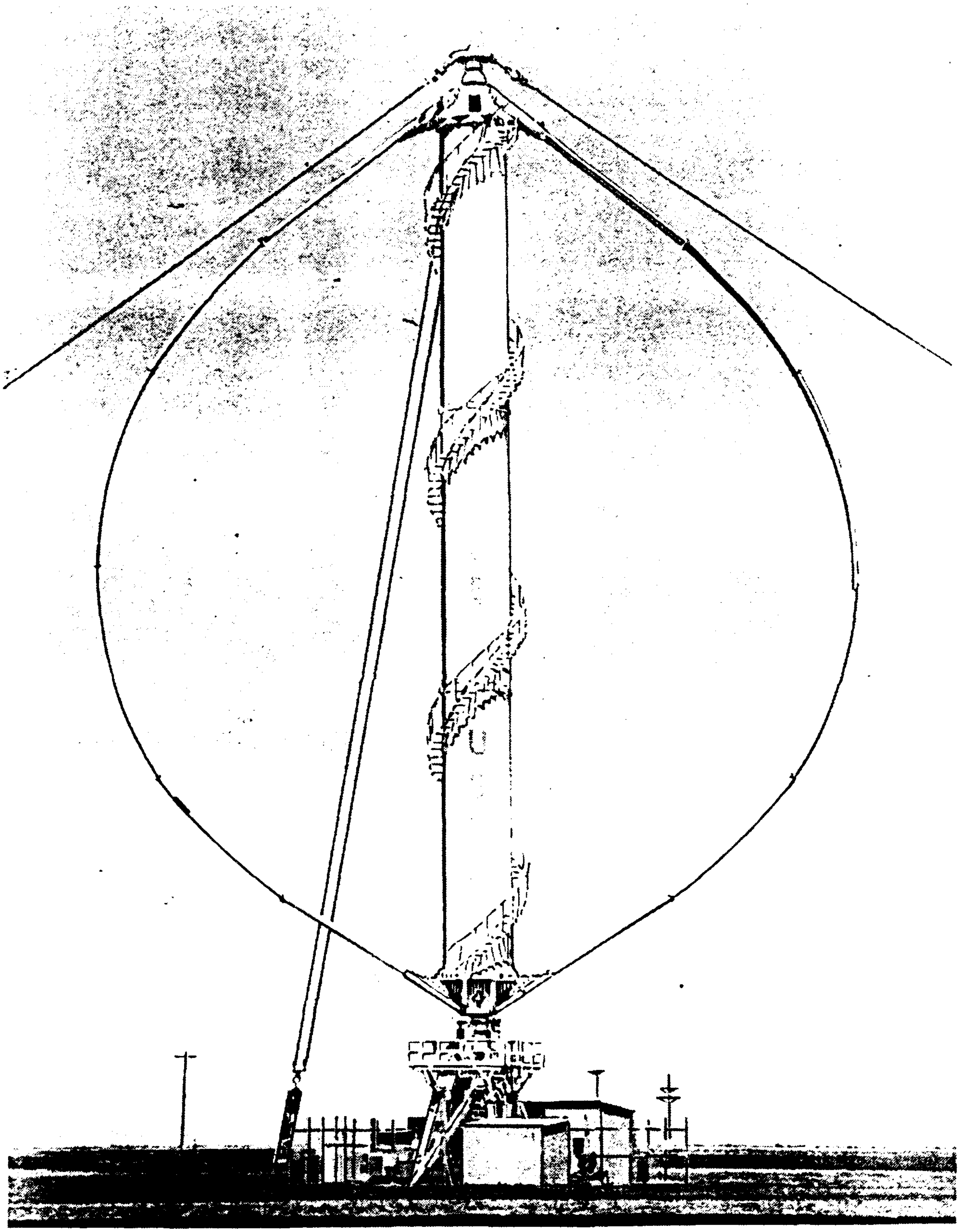


Figure 73. DOE/SANDIA 34-Meter VAWT Test Bed.

provided in Table 8. SNL is now working to obtain industrial partners for the design, manufacture, and marketing of a commercial version of this machine. Projected costs for wind-produced electric power, estimated by SNL and based on anticipated commercial turbine production, are compared with projected costs for conventional power generation in Figure 74.

11. Fuel Cells and Fuel Cell Cogeneration

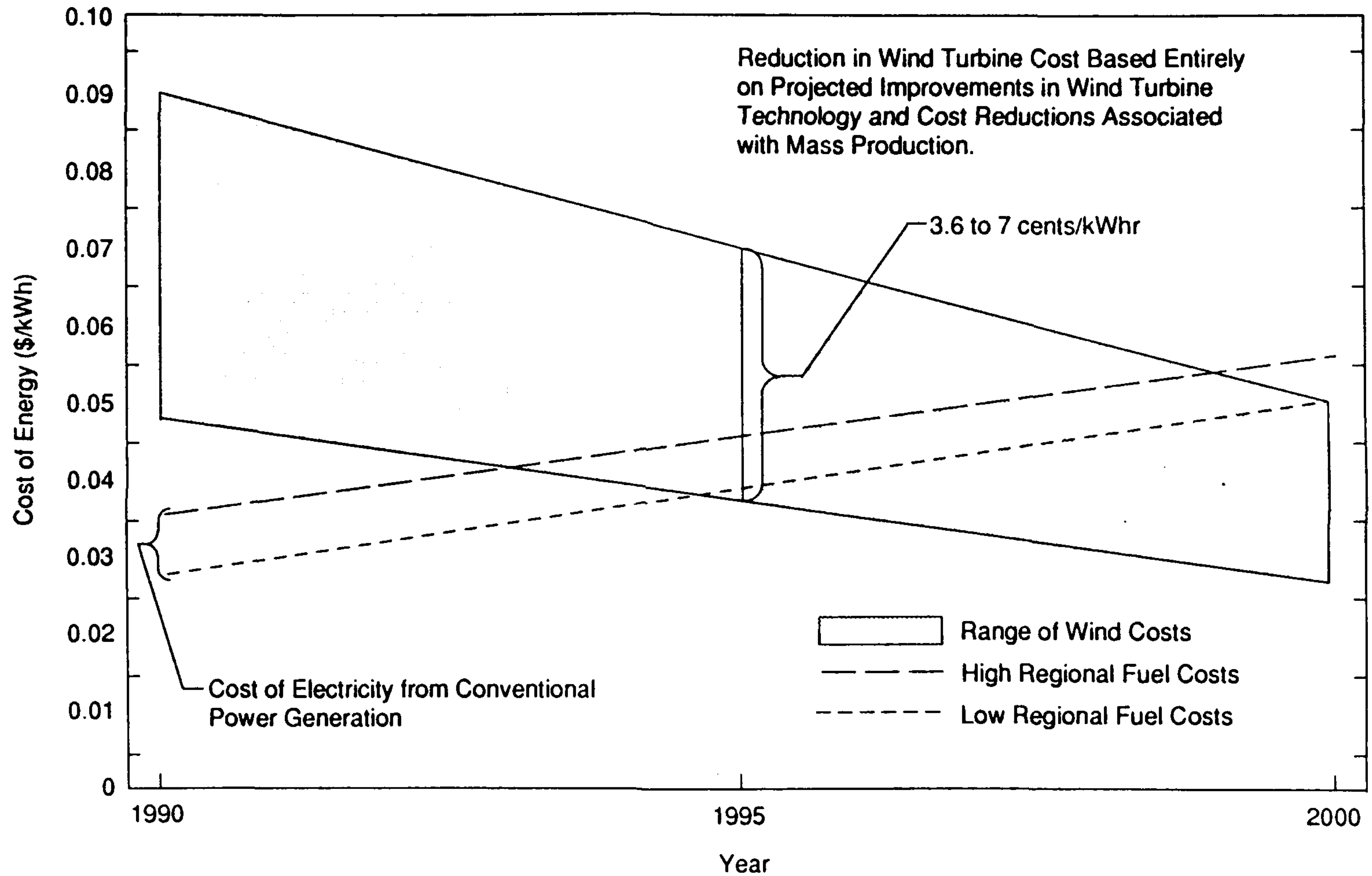
Major advances in the development of fuel cells have occurred over the past 10 years, driven mostly by space flight operational needs. They are also being considered for baseload electrical power generation for electrical utilities (Reference 58). Three major types of fuels cells that operate at three different temperature ranges are being studied for this application: phosphoric acid (PAFC) 204 °C (400 °F); molten carbonate (MCFC) between 538 and 704°C (1000 and 1300 °F); and solid oxide (SOFC) 982 °C (1800 °F). Fuel cells, in general, have greater, electrical conversion efficiencies (40 to 50 percent) than conventional steam turbine power plants. They can be operated with a variety of fuels, and they produce less pollution than conventional boilers.

A special type of solid-oxide fuel cell — a monolithic fuel cell — shows exceptional promise for rapid transfer to commercial use (Reference 59). This cell design uses a zirconium support tube encased within a solid positive electrode (Figure 75). A solid layer of zirconium surrounds the tubes and serves as the electrolyte. A third ceramic tube, the negatively charged anode, is bonded to the outside of the assembly. Cell components are fabricated in one piece similar to corrugated paperboard, which provides increased active surface area per unit volume of cell and a marked reduction in voltage loss. High current densities have been obtained as a direct result of the low internal resistance of these cells. The monolithic fuel cell is projected to be capable of operation in reverse mode so that the cell module can regenerate its own capability.

Fuels can be natural or synthetic gases. The high operating temperature 980 °C (1796 °F) allows the use of gases produced by coal gasifiers and provides the potential for combined heat and electricity applications in commercial buildings, as well as for industrial cogeneration and combined cycle operations in utilities. About 85 percent of the fuel in the cell stack will react electrochemically with 45 to 50 percent appearing as direct current. However, all the heat along with the energy content of the remaining 15 percent of the original fuel can be used to drive steam or gas turbines, raising overall plant efficiency from fuel to electric bus bar to 50 percent. Commercial-sized fuel cell stacks as large as 50 MW are considered feasible (Reference 60).

TABLE 8. OPERATING CHARACTERISTICS OF DOE/SANDIA 34 METER VAWT.

ROTOR	
DIAMETER, m	34
HEIGHT, m	50
GROUND CLEARANCE, m	7
SPEED, rpm	25 to 40
NUMBER OF BLADES	2
DIRECTION OF ROTATION (LOOKING UPWARD)	Clockwise
BLADE MATERIAL	Extruded Aluminum
BLADE LENGTH, m	56
AERODYNAMIC CONTROL	Stall Regulated
AIRFOILS	SAND 0018/50, NACA 0021
CHORD DIMENSIONS, m	0.91, 1.07, 1.22
SWEPT AREA, m^2	955
SOLIDITY	0.13
CENTRAL COLUMN	
Material	Aluminum
Diameter, m	3
Wall Thickness, mm	12.5
GUY CABLES	
Number	6
Material	Steel Bridge Strand
Diameter, mm	64
MECHANICAL DESIGN APPROACH	Modular
GEARBOX	
TYPE	Three-Stage Parallel
STEP-UP RATIO	47.5:1
RATING, kW	709
GENERATOR	
TYPE	Variable Speed, Synchronous AC
RATING, kVA	625
VOLTAGE	1200
SPEED, rpm	280 to 1900
FREQUENCY, Hz	60
CONTROLS	
SYSTEM	Programmable Industrial Controller
GENERATOR SPEED and TORQUE	Load Commutated Inverter
PERFORMANCE	
RATED POWER (ELECTRICAL) kW	500
RPM AT RATED POWER	37.5
WIND SPEED AT EQUATOR, m/s	
Cut-in	4
Rated	12.5
Cut-out	20
Survival	67
Annual Average	6.4
ANNUAL ENERGY OUTPUT (100 percent availability) MWh	1150
DATA ACQUISITION AND ANALYSIS	
NUMBER OF CHANNELS	128
MAXIMUM DATA THROUGHPUT RATE, kHz	200



Refs: DOE/Energy Information Administration,
Interlab White Paper

Figure 74. Cost of Energy Projections Wind vs. Peaking Fuel + var O&M.

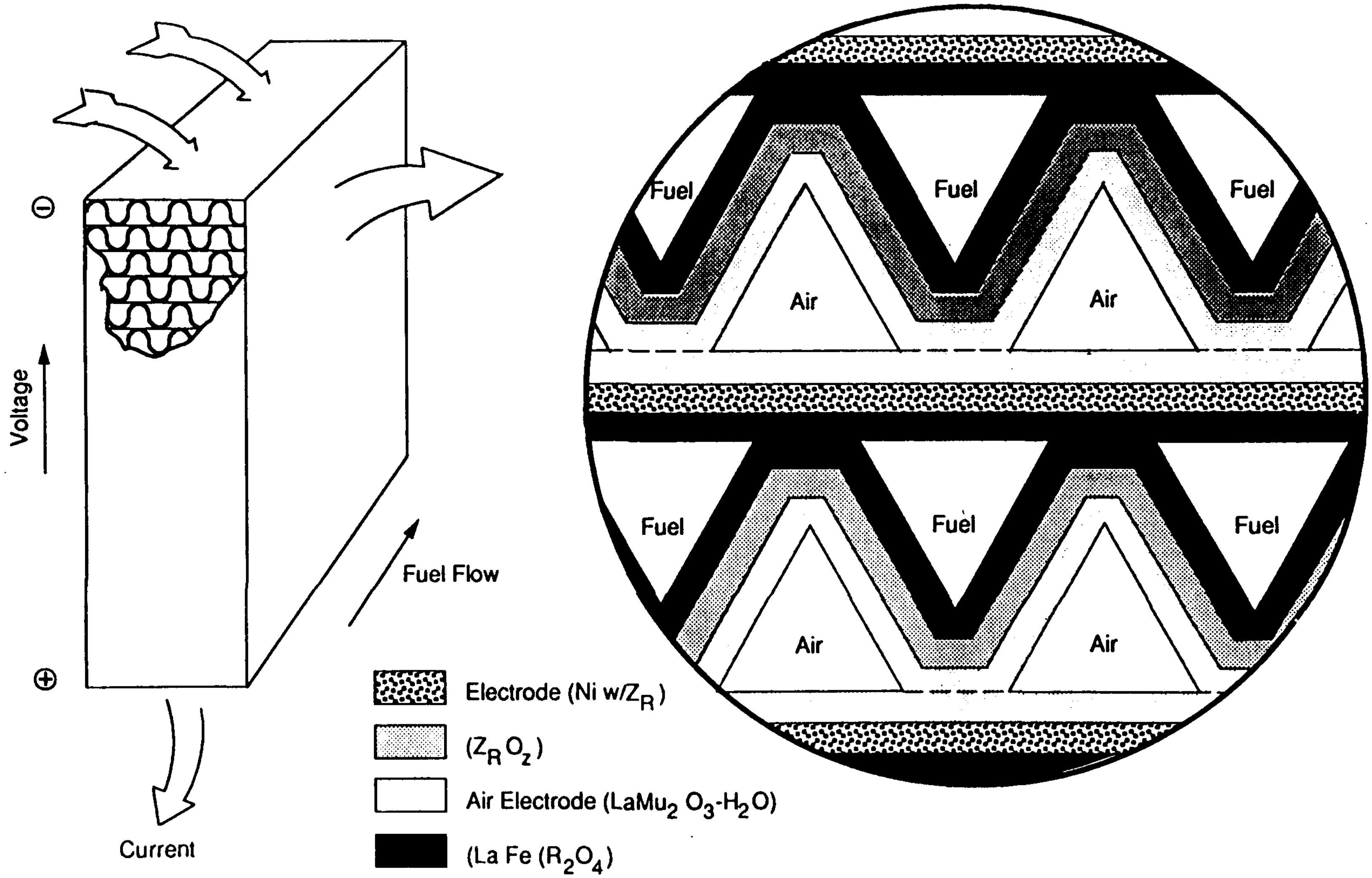


Figure 75. Fuel Cell.

Substantial testing of both molten carbonate and solid oxide fuel cells has been accomplished (Reference 61). Operational tests of 2000 and 10,000 hours in duration have been run on both bench-scale single MCFC cells and stacks of 5 to 10 cells with good performance still in evidence at the end of each test. A 10-kW stack development program with a process gas stack cooling system was accomplished in 1987. Fuel cells show great potential for use in a variety of vehicles as an improvement over internal combustion engines (Reference 62).

C. MID-TERM TECHNOLOGIES

1. Solar Photovoltaics

A substantial maturing of solar photovoltaic systems has occurred over the past several years, and more will occur within the next 10 years. Over the next 20 years, there will be increasing pressures for use of these nonpolluting systems by all agencies of the federal government. The recent development of the multilayered solar photovoltaic cell, with accompanying achievement of 31 percent conversion efficiency, is a significant breakthrough in solar photovoltaic technology and shows great promise for cost competitive, pollution-free electrical power (References 63 and 64). The development of amorphous silicon solar cells and associated improved manufacturing processes further supports this cost-reducing trend (References 19, pp. 8-9, and 65 through 67). Photovoltaic systems create no byproducts and thus have no environmental side effects. Such systems could then become highly cost competitive, lead to significant employment of solar photovoltaic systems in many sunny locations, and provide bulk power to utilities (References 6, pp. 26-27, and 68 through 70).

An effort to stimulate the use of solar photovoltaic systems for major utility applications has been initiated by the DOE (Reference 71). Photovoltaics for Utility Scale Applications (PVUSA) is a national cooperative research development project designed to demonstrate the viability of utility scale, photovoltaic electric generating systems. It provides a channel for commercial dialogue between utilities and the PV industry and a utility scale test bed for system level design, installation, operation and evaluation of both emerging PV module technologies and innovative, complete PV systems.

PVUSA began in 1986 with goals to assess promising photovoltaic technologies in a side-by-side utility setting, looking toward cost-effective commercialization in the 1990s, and to create a program to transfer the PV knowledge gained to government, the PV industry, and US utilities in order to encourage utilization of this renewable technology.

Phase 1 of the PVUSA Project is fielding a dozen different PV technologies. These systems total about 1MW peak AC output. The largest, a 400-kW system, will be completed in 1991 at under $5/peak watt. It has 120 kW of Emerging Module Technology (EMT) arrays in operations; 100 kW of this total is from five 20-kW arrays operated at the main Davis, CA site, with an additional 20-kW array operated by Maui Electric at Kihei, HI site. Additional Phase 1 contracts are in place to install 860 kW more at the Davis site and up to 100 kW more at host utility sites in New York, Virginia, and Texas.

Phase 2 of the PVUSA project, now being planned, will include additional pilot EMT and utility scale systems, which are scheduled to be installed and evaluated between 1992 and 1995. Continuation of PVUSA into Phase 2 will provide the evaluation and demonstration link between government and industry, improvements in manufacturing, and the eventual utility commercialization of photoutilities.

2. Thermophotovoltaics and Thermophotovoltaic Cogeneration

The use of a variety of solid state electronic devices to convert sunshine directly into electrical current was described in the above paragraphs. An interesting variation of this technology, called thermophotovoltaics (TPV), has been discovered and is now being developed.[1] Thermophotovoltaics (TPV) is the name given to direct energy conversion systems where a high temperature radiant heat source illuminates a photovoltaic (PV) cell to make electricity directly with no moving parts. A TPV power system can also produce useful auxiliary heat, thus becoming a cogeneration system (coproduction of electricity and heat from the single fuel).

TPV power systems were first proposed by Bruce Wedlock of MIT in 1963; however, because of the low efficiency of PV cells available at that time, TPV power systems were only able to produce system efficiencies of approximately 4 percent, and thus were not competitive with thermoelectric or thermionic power generation that could achieve 6 to 10 percent. Although some additional research was conducted on TPV in the intervening years, the low efficiency of directly irradiated PV cells (about 10 percent efficiency) has not allowed TPV power systems to be competitive (Reference 72). Because TPV power systems were viewed as low efficiency systems

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[1] "Recent Developments in Thermophotovoltaics," personal correspondence to Dr. Robert L. San Martin, Deputy Assistant of Energy for Conservation and Renewable Energy, from Dr. T. K. Feldman, Jr., Photon Research Corp., Albuquerque, NM, 11 March 1991.

in earlier studies, the Gas Research Institute (GRI), the US Department of Energy (DOE), and industry have not supported this technology in a significant way in their energy R&D plans.

During the past two years, three new developments have occurred that could greatly improve the efficiency of TPV power systems. The first new development is that of high efficiency PV cells. PV solar cells developed at Sandia National Laboratory, at the Solar Energy Research Institute (SERI), at Stanford University, and at the Boeing Company have all achieved efficiencies in concentrated sunlight of over 31 percent. Recent developments at SERI and Boeing indicate that narrow bandwidth PV cells can achieve 40 percent efficiency in concentrated sunlight.

The second new development is an optical filter/reflector that can transmit radiant energy in a narrow bandwidth, while reflecting the remaining energy. Such optical filter/reflectors have been developed by Dr. David Pelka of the Physical Optics Corporation, in Los Angeles, CA, and others. This type of optical filter/reflector, when matched to a TPV power system, greatly improves system efficiency by transmitting only the bandwidth of wavelengths that are most efficiently converted by the PV cell and reflecting the remaining energy back to the heat source, where it is conserved to help maintain the temperature of the heat source. The matched optical/filter reflector will allow the TPV system to achieve an efficiency significantly higher than is possible with sunlight, where energy reflected back to the sun is lost rather than conserved.

The third new development is the invention of gas-fired TPV power systems with an integral recuperative heat recovery heat exchanger. David Pelka has invented and patented a highly cost-effective, pebble bed recuperative burner that will allow gas-fired TPV systems to be cost-effective. Others have independently invented different versions of recuperative gas-fired TPV power systems. A new company, Photon Research Company (Photon) has been formed to develop the recuperative TPV technology.

The US has over 50 years of domestic natural gas supplies, and gas is clean burning and widely available. A properly designed recuperative heat exchanger will allow recovery of 80 to 90 percent of exhaust waste heat from the TPV system, which significantly improves the overall system efficiency. The recuperative heat exchanger can also be designed to provide waste heat for cogeneration heating applications.

When these three new developments are applied to the TPV power system, it is expected that TPV system efficiencies of 40 percent can reasonably be expected. When the cogeneration feature is added to such a high-efficiency TPV system, overall energy use efficiency can reach 80 to 90 percent (electricity plus useful heat). Although no thorough analysis has been conducted, simple analyses by the Brooklyn Union Gas Company indicate that gas-fired TPV cogeneration systems could produce power for approximately $0.07/kWh. The availability of this cost-effective and clean-burning cogeneration system, which uses plentiful domestic gas, would have a substantial impact on the US economy, environment, and energy security.

At a recent TPV research review and planning meeting, experts from the government, industry, military, and federal laboratories reviewed the recent progress in TPV technology. It was concluded that TPV systems operating with a 2000 °C (3632 °F) radiator and an effective filter/reflector could achieve 40 percent efficiency with high-efficiency silicon cells and 50 percent with GaAs cells now available.[1] It was also concluded that with the low band gap PV cells being developed by SNL and SERI, it was not overly optimistic to expect that lower temperature TPV systems could also achieve efficiencies over 30 percent. A multiphase R&D program is needed to continue development of these higher efficiency TPV power and cogeneration systems is needed.

3. Clean Coal Technologies

About 800 million tons of coal are burned every year in the US, producing almost 60 percent of US electricity (Reference 73). With vast reserves worldwide, coal will continue to furnish a large proportion of the primary energy for electricity generation for many years. Emissions from US coal-fired power generation and industrial coal burning constitute about one-third of all national CO_2 emissions. Much of the recent concern over energy and the environment has been focused on coal, the image of which has traditionally been one of dust and grime, degraded hillsides, mining catastrophes, and chimneys emitting black smoke. Research and development in producing energy from coal with less impact on the environment is increasing (Reference 74). New "clean coal technologies" include precombustion cleaning, better combustion processes, postcombustion technologies (scrubbers, filters), and conversion into gas or liquid fuel before being burned. A major vehicle for these developments is the federal Clean Coal Technologies Demonstration Program, begun in late 1985, which has resulted in 38 demonstration projects with a total value of $3.2 billion now funded or under negotiation with the Department of Energy.

[1] "A Review of Thermophotovoltaic Power System Design," personal correspondence from Dr. P.A. Basore, Photovoltaic Technology Research Division Sandia National Laboratory, Albuquerque, NM to J. Chini, Southern California Gas Co., El Monte, CA, and D.L. Noreen, Brooklyn Union Gas Co., Brooklyn, NY, 29 January 1991.

DOE and the private sector are conducting experiments on coal-fired gas turbines (Reference 75). Another DOE project to develop diesel engines that burn a mixture of coal, water, and methanol may impact the transportation sector and could also have application for generating electricity on a small scale, possibly for airbases. Experiments are also underway in the conversion of coal to a liquid fuel and indirect conversion to gasoline (References 22, pp. 17-18, and 76). Oil made from coal could be an energy option for the future, thereby reducing US dependence on foreign oil.

Five new pollution-reducing coal technologies ready for implementation under DOE's Clean Coal Technology Program are the following: (1) a process that captures the three main air pollutants from coal burning in a single high temperature baghouse, unlike required conventional scrubbers, which remove only sulfur pollutants; (2) a scrubber that uses a chemical catalyst to remove 90 percent of the nitrogen and sulphur-containing pollutants in flue gas before it is released from the stack; (3) a scrubber that uses limestone to absorb sulphur at twice the flow rate of conventional scrubbers and at half the cost; (4) two processes that could cut nitrogen oxide emissions in half by changing the combustion process used by about 40 percent of all US coal-fired utility boilers; and (5) a scrubber that cleans coal-fired cement kiln gases using discarded waste materials (Reference 77).

Research on the use of large utility-scale, fluidized-bed boilers, which can burn a variety of coals and still meet federal emission standards, may make it more economically feasible in the future to utilize coal as a fuel source (References 22, pp. 17-18, and 77).

One way to use coal more efficiently while reducing pollution is through a pressurized fluid bed combustion (PFBC) combined cycle process. A new PFBC plant becoming operational at Ohio Power Company's Tidd Plant on the Ohio River is capable of reducing SO_2 emissions by more than 90 percent and NO_x emissions by 50-70 percent (Reference 78). The combined cycle feature has a thermal efficiency of 45 percent compared to a conventional 36 percent. Another technology is the Encoal mild coal gasification project, which converts a subbituminous low-Btu coal into a useful higher Btu solid while producing significant amounts of a liquid fuel. Encoal Corporation will design, construct, and operate a 1000 ton/day demonstration plant at the Buckskin Mine near Gillete, WY, to test this method.

PSI Energy, Inc., Indiana's largest electrical utility, in partnership with Destec Energy, Inc., plans on developing a large clean coal project that could be a model for responding to the Clean Air Act (Reference 79). The utility will build a 230-MW power plant consisting of repowering an existing unit in West Terre Haute into a combined cycle installation. Destec developed the gasification technology and is designing the plant. The process is expected to remove 98 percent of the sulfur from the coal.

4. Alternative Fuels

Efforts to improve the nation's air quality is causing increasing pressure to use alternative fuels (References 78 and 79). The continuing national concerns regarding both the US dependence on foreign oil supplies and the impact of the use of fossil fuel on the environment are providing the impetus for the transportation sector to begin the switch from gasoline to nonpetroleum-based fuels (Reference 80). DOE has conducted a methanol vehicle demonstration program, introducing methanol-powered vehicles into the civilian federal fleet (Reference 81). The program has apparently met with limited success, partially because of the unavailability of sufficient methanol on the market.

Metropolitan areas are beginning to adopt regulations that require conversion of fleet vehicles to alternative fuels, which release lower levels of pollutants than gasoline (References 82 and 83). There will likely be continued research on blended fuels and flexible fuels.

5. Nuclear Fission

Only two decades ago, nuclear fission looked like the best choice for the energy of the future. Today, that future is clouded (Reference 12, p. 112). The problems with fission power are radioactivity and concern for nuclear accidents. In a fission reactor, about 7 percent of the fission energy is not released immediately, but remains in the form of radioactive nuclei in the fuel to be released later as nuclear radiation, most of it in a matter of days. Enough radioactivity remains, however, to cause problems for tens of thousands of years.

"Used" nuclear fuel is so radioactive that it must be kept out of the environment at all cost. After "used" fuel is removed from a reactor, it is stored underwater at the power plant for several years until the temperature is low enough for safe shipment. Next, it is reduced to a sludge and stored in underground holding tanks for decades. In the US, current plans call for reducing the wastes to solid blocks that resemble glass or rock, to lock the radioactive substances into solid structures. Finally, these structures are to be buried in special underground tombs. There are special requirements for this entombment. Water could still dissolve parts of the solids and carry them away, so the solids must be buried in a place that can never be reached by groundwater.

Nuclear burial grounds seem a terrible burden to leave to future generations. However, given the hugh stockpile of wastes already on hand, we have no choice but to create them. France has shown that with careful central planning and training, it is possible for a nation to generate most of its electric power from nuclear fission with reasonable safety.

6. Stirling Engines

A Stirling engine is another form of heat engine[1] invented by the Stirling brothers (Reference 84). A simplified diagram of a Stirling engine is shown in Figure 76. A Stirling engine normally contains a displacer piston, a power piston, a high-temperature (heated) gas zone, a low-temperature (cooled) gas zone, and a working gas, normally hydrogen or helium. To operate the Stirling engine the displacer piston is moved back and forth causing a constant volume displacement of the working gas back and forth between the heated zone and the cooled zone. When in the heated zone the working gas is heated, increases in pressure, and provides a pressure force to move the power piston in a power stroke. At the end of this stroke the displacer piston is shifted causing the working gas to move into the cooled zone where it is cooled and the pressure reduced, thus lowering the pressure on the power piston for the return stroke. This heating and cooling of the working gas is repeated in a cyclic manner causing the pressure on the power piston to be alternately increased and decreased. The displacer piston is mechanically coupled to the power piston to move at the correct time in the cycle. Several such piston/displacer arrangements can be fashioned together to produce a smooth-running engine where the only input is heat at one location on the engine and a heat sink (cooling) at another location.

Many different variation of the basic Stirling engine have been built and operated over the years (Reference 85). The Stirling engine can also be run backwards, that is, where mechanical work is input to the engine to pump heat energy from a cooler location uphill to a higher temperature location (References 84 and 85). It can thus be used as a refrigeration system. For many years, Stirling-cycle refrigeration systems have been employed in military and industrial applications at cryogenic temperatures (Reference 86). In spite of these applications and numerous variations, the Stirling engine has never gained popularity in competition with the many other heat engines (steam piston, steam turbine, gas combustion turbine, reciprocating gasoline, reciprocating diesel, etc.) and thus has been relatively little used.

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[1] Heat engine — Any thermal/mechanical system that converts thermal energy directly into mechanical power.

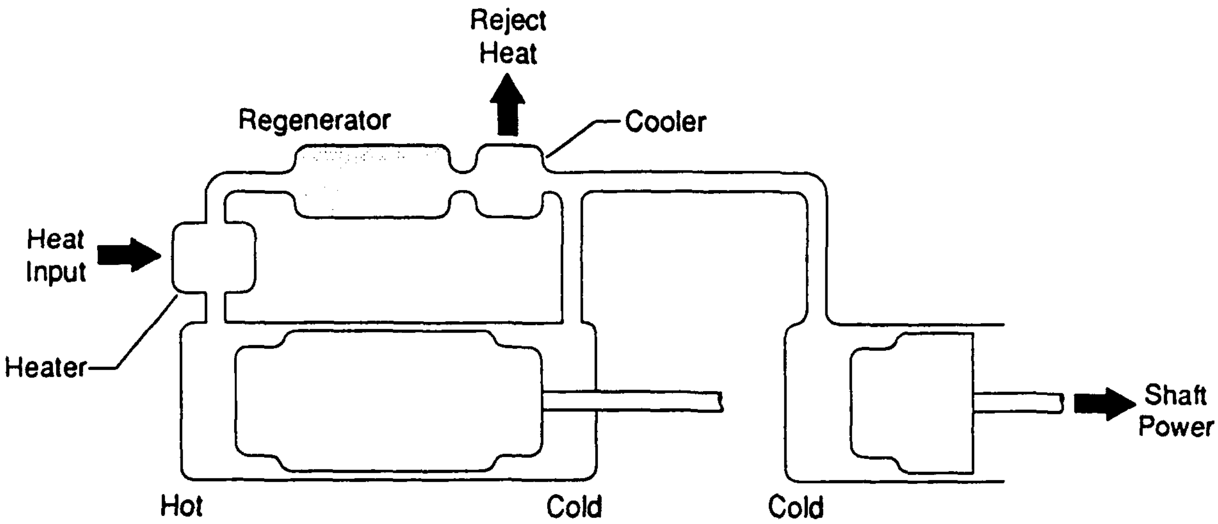

Figure 76. Simplified Schematic of a Stirling Cycle Heat Engine.

Two recent adaptations of the Stirling engine show promise of providing innovative energy systems useful to society and comparable in cost with competing systems. The first is a solar-heated, air-cooled, Stirling engine-powered electrical generator (Reference 87). The system uses a parabolic dish, concentrating solar collector to focus sunlight onto a small Stirling engine mounted at the focus of the parabolic dish. Heat pipes are used to absorb the high-temperature energy from the concentrated sunlight and transfer it into the working gas at the heated zone interior of the engine. Convective currents of ambient air (or wind) provide the cooling. A linear alternator, constructed integrally as part of the engine, converts the mechanical power produced by the engine directly into electricity. A dual-axis tracking system keeps the parabolic dish constantly positioned so that the maximum available sunlight is focused on the engine. Thus, when the sun shines, electricity is produced. Prototypes for two sizes of this system, generating 5 kW and 25 kW, have been constructed and are being tested.

The second new application of Stirling technology is an improved refrigerator. Environmental concerns (discussed previously in Section III) have led to restrictions on the use of chlorofluorocarbons (CFCs), which are the common working gases used in most of today's vapor-compression refrigeration systems. The working gases in most Stirling engines are lightweight gases such are hydrogen or helium, which are not "greenhouse gases." Thus, a new Stirling-cycle refrigeration system that does not use CFCs can possibly gain a competitive advantage over conventional systems. Prototype Stirling-cycle replacements for the common household refrigerator are being developed and tested (Reference 88). If successful, larger Stirling-cycle refrigeration systems may follow.

D. FAR-TERM TECHNOLOGIES

1. Hydrogen Fuels

Of all the elements in the world, hydrogen is unique. It is one of the very few elements that can be used by man to store energy in an easily recoverable manner. It can be produced from a variety of other energy sources, transported and stored in several different forms, and used for a multitude of purposes including transportation fuels; thus, it could very quickly help reduce our national dependence on foreign oil imports. Most remarkably, when burned to recover its stored energy, hydrogen produces mostly water--making it the cleanest burning fuel known. The use of hydrogen continues to be urged as a solution to the many energy-related environmental problems now facing our world.

The chemical, physical, and thermodynamic properties of hydrogen are well known (Reference 89). It can be easily produced from a variety of other energy sources using several different processes (Reference 90). A most common way of producing hydrogen is by electrolysis of water using electricity. Several commercially available variations of this process use electricity supplied by utility companies to produce significant quantities of hydrogen. At this time, however, electrolysis is not the least expensive way to produce hydrogen. Chemical production methods that use natural gas as the feedstock for hydrogen production are currently the least costly approach. Hydrogen can also be produced from coal. All production from fossil fuels produce some environmentally undesirable waste products such as carbon dioxide. Electric power from renewable energy sources (hydroelectric, wind, solar thermal electric, photovoltaic, etc.) can also be used to produce hydrogen, thus providing a means for storing some of these more randomly generated renewable energies (Reference 91). Work on developing new, improved methods for producing hydrogen continues in many sectors (References 92 through 94).

Hydrogen can be stored and transported as a gas, a liquid, or in chemical combinations with other materials, usually as metal hydride (Reference 95). Storage and transportation as a gas require high-pressure storage tanks, similar to those used for propane, and pressurized pipelines similar to natural gas lines. In fact, the use of existing natural gas pipelines for transporting hydrogen gas has been studied and is considered feasible. As a liquid, storage and transportation of hydrogen essentially comprise a cryogenic process, much like that used for other cryogenic liquids (liquid oxygen, liquid nitrogen, etc.). Storage and transportation primarily require exceptional insulation to avoid heat transfer to and vaporization of the liquid hydrogen. To store and transport hydrogen as a hydride, a pressure vessel is filled with a granular form of an acceptable metal material (e.g., magnesium). Hydrogen gas is forced into the tank under substantial pressure. The hydrogen reacts with the metal to form a metal hydride (magnesium hydride), a relatively stable compound. During this process large amounts of heat are given off, which must be transferred away for the hydride formation process to go to completion. To reverse the process, the pressure is reduced to ambient levels, and heat is applied. The metal hydride then gives up its hydrogen and remains as the original material. This process can be repeated hundreds of times with little deterioration of the system.

A multitude of uses for hydrogen have been envisioned, studied, tested, and evaluated (Reference 96). It is most often thought of as a transportation fuel. Numerous hydrogen-powered cars, buses, and other motor vehicles are currently in service, with modifications to both normal gasoline or diesel engines (References 96 and 97). Conceptual designs for hydrogen-powered trains have been developed, evaluated, and shown to be highly feasible (Reference 96). Hydrogen-powered airplanes have been studied extensively and shown to be very attractive (References 96 and 98). The use of hydrogen as propellant for space launch vehicles is today commonplace. The space shuttle orbiter vehicles all use liquid hydrogen and liquid oxygen as their primary fuels. Hydrogen is the basic feedstock for many industrial chemical operations. Finally, the use of hydrogen for common household purposes (appliances, hot water, cooking, space heating, etc.) has been well studied and found to be very workable.

The safety, social, economic, and legal aspects of an extensive use of hydrogen (the so-called "hydrogen economy") have also been thoroughly studied (Reference 99). With regard to safety, hydrogen has been found to be no more dangerous for common, everyday use than natural gas, propane, or gasoline. Some new equipment, procedures, and safety rules will have to be developed and enforced, comparable to what is done with the other fuels mentioned above. Economically, hydrogen is still more expensive than fossil fuels. The situation however, is expected to change as improved hydrogen production methods are developed, as national petroleum resources diminish, and as environmental constraints for fossil fuels grow. Socially, the enthusiasm for using hydrogen as a transportation fuel is growing (References 100 and 101), and a recent study forecasts the beginning of a shift from fossil fuels to hydrogen by the year 2000 (Reference 102). There are many signs indicating that hydrogen will become the "fuel of the future."

2. High-Temperature Superconductivity

Superconductivity is the ability of a material to carry the flow of electrical current with essentially no resistance. It is a new technology that has the potential for causing real changes in electrical power systems (References 103 through 105). The phenomenon, first discovered in 1911, required that the material — mercury — be cooled to near absolute zero (-273 °C, 0 °K) (Reference 106), which could only be achieved with liquid helium, thus making the process very difficult and costly. More research from 1930 to 1970 using compounds of niobium raised the temperature at which superconductivity occurred to above 20 °K (-253 °C). In February 1987 researchers at IBM of Switzerland achieved superconductivity with compounds of yttrium at the remarkably high temperature of 94 °K (-179 °C). What made this achievement so remarkable was that this temperature was 17 °K higher than the temperature at which nitrogen freezes. Thus, for the first time superconductivity could be achieved using liquid nitrogen, a low-cost, plentiful material, as the cooling agent. This discovery started a flurry of research activity seeking to discover other high-temperature superconducting materials and to fashion them into useful devices (Reference 107). Since then superconductivity has been achieved using compounds of thallium at temperatures of 125 °K (-148 °C).

Superconductivity occurs because of a distortion of the atomic lattice structure of the material at these low temperatures. Normally, an electron current is composed of single electrons flowing through the lattice. Resistance occurs as electrons collide with small impurities and cracks in the lattice-like atomic architecture of the material. The electrons can also collide with the vibrating atoms themselves, each collision expending energy and giving off heat. When the material is cooled down to the superconductivity state, the passage of a negatively-charged electron between two positively-charged atoms causes the atomic lattice to distort and the atoms to move closer together. This distortion of the lattice creates a region of enhanced positive charge, which then attracts a second negatively charged electron to that area. The two electrons, called a Cooper pair, become locked together and will travel inseparably through the material as long as a current exists. The Cooper pairs are held together not only through their own indirect attraction but also because of the electron pair in front and behind, all flowing along in tight formation. As the atoms of the lattice oscillate forming positive and negative regions, the electron pair is alternatively pulled together and pushed apart without collisions, resulting in efficient flow of the current called superconductivity.

To be useful for practical applications, a superconducting material must have a variety of attributes. It must achieve superconductivity at temperatures high enough for practical use (in the liquid nitrogen range or higher), it must continue to function as a superconductor in the presence of large magnetic fields, and must, simultaneously, be able to carry large electrical currents. The material must be formable, in cost-affordable processes, into useful shapes and configurations (wires, tapes, cylinders, etc.). The materials in these shapes must have adequate mechanical properties (tensile strength, flexibility, etc.) to be used in the fabrication of useful devices. Finally, the materials must retain these properties and characteristics for a long time when exposed to the environment in which they must be used or stored. A great amount of research has been accomplished over the last few years and is currently ongoing in an effort to achieve these capabilities.

Many devices based on the use of these superconducting materials have been studied, and some have been tested. Reduction of resistance losses in transmission lines and transformers is considered a prime opportunity. Superconducting magnetic energy storage (SMES) is one of the more promising applications. Giant superconducting magnetic rings, constructed underground, are envisioned to be charged with electrical current where it circulates endlessly with no resistance. When needed, the electrical current could be recovered and put to work. The development of highly efficiency motors, fabricated from superconducting materials, also appear to be possible as does the manufacturer of many other electrical and electronic system components. Finally, new computers which use superconducting circuits, offer the potential for vastly increased computing speeds and storage (References 108 and 109). Such computers could enhance the usefulness of artificial intelligence for a multitude of applications. IBM, AT&T, DARPA, the Air Force's Wright Laboratory, numerous universities, and a host of other companies are all working diligently to bring this very promising technology to fruition. It will likely be 7 to 10 more years before the first of such devices go into major production.

3. Nuclear Fusion

Fusion reactions occur when the nuclei from two individual atoms are brought into very close proximity (Reference 12, p. 118). They react to form a simple new atomic nucleus accompanied by the release of large amounts of energy.

The most promising fuel for fusion reactions is deuterium, an isotope of hydrogen that is twice as heavy as ordinary hydrogen. Only one hydrogen atom in 7000 is a deuterium atom, but a 1 million kW electric power plant — equivalent to the largest fossil fuel or fission plant now in service — would consume less than 28 ounces (800 grams) of deuterium each day. Scientists estimate that there is enough deuterium in the world's oceans to provide all our current energy needs for several million years, at the end of which sea levels will have dropped only about 1 foot. And this would not end the use of controlled fusion as an energy source. Deuterium is not the only fuel suitable for fusion; it is merely the easiest to use.

All experimental fusion devices have the same goal — to bring nuclei close enough together to fuse. For two nuclei to fuse, they need not actually touch, but they must come extremely close to contact. A usable amount of fusion would occur in deuterium fuel if its nuclei came within 5 billionths of a millimeter of each other. It is difficult to get nuclei this close because particles with like charges repel one another. Nuclei have positive electric charges, and their mutual electrical repulsion tends to keep them apart. At temperatures and pressures normally encountered on earth, nuclei hardly ever get close enough to fuse. In a hydrogen molecule, for example, the nuclei of the two atoms that make up the molecule stay 76 billionths of a millimeter apart. The core of a star, for example, can reach millions or billions of degrees. At such temperatures, atoms move so swiftly that nuclei approach to within 1 billionth of a millimeter of one another.

There is no way to maintain such temperatures in a fusion device for more than an instant. These temperatures are high enough to turn any solid structure into vapor. Scientists hope to achieve ultrahigh temperatures for an instant, producing many brief pulses of fusion energy. The walls of the reactor would then remain at a much lower temperature than the reacting fuel. The deuterium in a reactor must not touch the walls, however. Nuclei that touched walls would instantly become too cool to fuse. In fact, the problem of confining nuclei so that they do not touch reactor walls is one of the main challenges of fusion research.

There are two approaches to this problem — magnetic confinement and inertial confinement. Magnetic confinement makes use of the fact that the deuterium fuel is electrically charged. At high temperatures, hydrogen atoms come apart, producing a state of matter called a plasma, consisting of positively charged nuclei and negatively charged electrons. These particles can be manipulated by magnetic fields generated by huge and expensive machines. The goal of magnetic confinement is to lock the plasma in a "magnetic bottle" that pushes the plasma away from the walls of the container. Unfortunately, a plasma cannot be bottled up for long, because moving electrons create magnetic fields that disrupt the fields generated by the machine.

At present, the mightiest fusion machine is a $300-million magnetic-confinement device, the Tokamak Fusion Test Reactor in Princeton, NJ. In three years of operation, this machine has approached — but never reached — scientific breakeven, the point at which the reactor produces as much energy as it takes to heat it.

Inertial confinement is a newer approach in which converging beams of laser light or subatomic particles heat and compress a pellet of solid hydrogen. This is how a hydrogen bomb works, with a nuclear fission device supplying radiation that compresses the fusion fuel. A fusion reactor working on this principle would produce repeated miniature nuclear explosions, each with the energy equivalent of a few pounds of high explosive rather than millions of tons. At present, inertial confinement devices are much further from scientific breakeven than are the magnetic confinement machines.

At the beginning of the fusion effort in about 1950, optimists predicted scientific breakeven within five years. Today they are making the same estimate, which prompted one pessimist to remark that "fusion is the energy source of the future, and always will be."

Even if researchers achieved breakeven, there would still be some problems. Fusion reactions generate neutrons, a nightmare for machine designers. As neutrons fly through matter, they dislodge atoms, weakening any solid material. Consequently, they would weaken reactor walls, which eventually would have to be replaced. Some neutrons are absorbed by nuclei of various materials that then become radioactive, so the "used" walls would be somewhat radioactive. Thus, although fusion reactors would create less of a waste disposal problem than do fission reactors, the problem would still be a serious one.

4. Cold Fusion

In March 1989, chemists Martin Fleischmann of the University of South Hampton (England) and B. Stanley Pons of the University of Utah startled the world by claiming that they had produced fusion at room temperature (Reference 12, p. 121). The two chemists said that fusion had occurred in a simple, common chemical apparatus called an electrolytic cell, with two electrodes. The negative terminal was made of the metal palladium and the positive terminal of platinum. The researchers mounted the electrodes in a glass vessel containing heavy water, whose molecules contained oxygen and the deuterium isotope of hydrogen.

When the scientists connected the electrolytic cell to a source of electricity, water molecules split into positively charged hydrogen atoms and negatively charged oxygen atoms. Because unlike charges attract, hydrogen atoms flowed to the negative electrode and oxygen atoms headed for the positive electrode.

In cells using common electrode materials such as carbon, the hydrogen and oxygen atoms bubble to the water's surface as gases. A palladium electrode attracts hydrogen so strongly, however, that the electrode can store a great deal of hydrogen in the spaces between its palladium atoms. Fleischmann and Pons had reasoned that once enough hydrogen atoms had been taken up by the palladium, they might be packed close enough to produce fusion. The two chemists reported that, after a few weeks of operation, their cell began to produce much more heat than the electric current could have provided. Furthermore, they claimed to have detected neutrons, though at a rate 1 billion times smaller than expected if the heat had been produced by the common fusion reactions. (There are fusion reactions that emit no neutrons, but under normal conditions they are far less likely to occur than are the reactions that do emit neutrons.)

Hundreds of scientists rushed to conduct electrolytic-cell experiments to check the results reported by Fleischmann and Pons. A few researchers claimed — like the Utah chemists — that their experiments produced more heat than could have been provided by the electric current supplied to the electrolytic cells. Other scientists observed neutrons. The vast majority, however, saw no evidence of fusion at all. Efforts to check Fleischmann and Pons's results were complicated by the fact that the two chemists released few details because the University of Utah wanted to guard the patent rights to their discovery.

Even if the Utah chemists' results turn out to be incorrect, their work has encouraged scientists to reexamine other approaches to fusion. One approach employs unstable atomic particles called muons, which are similar to electrons but 200 times heavier; and deuterium molecules, which are made up of two deuterium nuclei and two electrons in orbit about the nuclei. Scientists create muons in the laboratory and then guide them into a chamber containing deuterium molecules. A muon tends to replace one of the electrons in a deuterium molecule. When this happens, the molecule shrinks to 1/200 of its normal size and the two nuclei fuse. The muon then usually replaces an electron of another deuterium molecule, and fusion again takes place.

In almost all cases, however, after a few repetitions of fusion reactions, the muon disintegrates or goes into orbit around one of the fusion products such as a helium nucleus. Unfortunately, the fusions caused by the muon do not generate enough energy to make up for the energy used to create the particle. Scientists hope to find a way to minimize the absorption of muons by fusion products.

In conclusion, neither the muon approach nor any of the others — magnetic confinement, inertial confinement, or "cold" fusion — promise to provide abundant fusion energy in the near future.

SECTION VII
PROJECTION OF NEW TECHNOLOGIES TO MEET AIR FORCE NEEDS

As many of the new technologies discussed in Section VI mature they could be employed to help meet AF facility/utility energy needs over the next 30 years. How rapidly the technological transitions occur depends on many factors (changing world energy situations, investments in R&D and subsidies for emerging systems, intensity of environmental pressures, etc.) and would be extremely difficult to estimate quantitatively. Some may require further R&D to be suitable for the special needs of military operations. Several of the technologies more likely to be applied in widespread use, and those which could help ease airbase energy problems, are discussed below.

A. NEAR-TERM TECHNOLOGIES

1. Energy-Effective Building Technologies

Many energy-effective building technologies are already mature and ready to be employed by the Air Force for new facilities' construction or rehabilitation of existing facilities. Passive solar designs can be immediately appropriate for a great many facilities without marked departure from more traditional construction trends. For example, many facilities are constructed using masonry blocks as the primary structural component. These materials can readily be used to store solar energy collected during daylight hours. For optimum benefit, insulation should be installed on the exterior of the block wall, a new trend which is just now being recognized throughout the AF. A new AAFES commissary building was recently constructed on Kirtland AFB, NM, using this technique. A new series of passive solar design handbooks specifically tailored to meet USAF design needs has recently been published and distributed by Headquarters USAF (HQ AF/LEED) (References 110 through 112). The state of the technology is sufficiently mature and the benefits great enough that passive solar designs and other energy-effective building technologies should be seriously considered for every new AF facility planned for construction. There is, however, a major problem with this approach. Current federal policies mandate that the lowest cost designs be used even though such designs will lead to much greater energy consumption and associated costs over the life of the facility. Passive solar or other energy effective designs often incur increased initial costs and thus are usually eliminated even though those increased capital costs will likely be offset by reduced operating costs within a short time. For the AF to benefit from the available energy-effective building technologies, these design policies must be modified.

2. Lighting Systems

Major portions of many airbases remain brightly lighted all night long, either for security reasons or because the lights were not turned out when work was finished. During daylight hours the lights in many areas inside of buildings (hallways, restrooms, closets, etc.) remain on even though there is seldom anyone there. The new lighting technologies described earlier in Section V could be employed to help reduce the consumption of electricity and associated costs.

3. Cogeneration

Cogeneration is clearly a rapidly maturing technology that can contribute quickly to airbase energy needs. Numerous cogeneration plants are already in operation in the private sector, and complete systems, including small packaged units, can be readily purchased from and installed by commercial vendors. Many airbases offer the necessary conditions for an ideal match with cogeneration systems. Onbase cogeneration plants increase utility system reliability and offer a cost-effective way to increase energy security for the base. Many airbases have central steam distribution systems and a demand for more thermal energy than electricity. They also usually have available land on which to locate cogeneration plants. Both energy reduction and cost saving, as shown in Section V, can be substantial if appropriate circumstances and energy costs currently exist at the airbase. Annual savings of as much as \$1M per base are potentially achievable through cogeneration (Reference 113).

For example, Kirtland AFB, NM, has substantially larger thermal energy loads than electric power loads, as shown by consumption of natural gas and purchased steam (Figure 77). A cogeneration plant could be used to provide nearly all the electrical load (approximately 370,000 MBtus per year) and produce a substantial portion (approximately 648,000 Mbtus) of the total 960,000 MBtu annual thermal load as a byproduct. Based on the analyses described in Section V and current energy product prices, cost savings of approximately 35 percent (over \$3.5 M) could be possible (Figure 78). If third-party financing were to be used a large portion of these savings would necessarily be shared with the third-party energy company but significant savings for the airbase could still be achieved. A review of the DEIS data (presented in Volume II) shows many AF airbases where the consumption of natural gas (thermal load) is much greater than the electrical load indicating substantial potential for cogeneration.

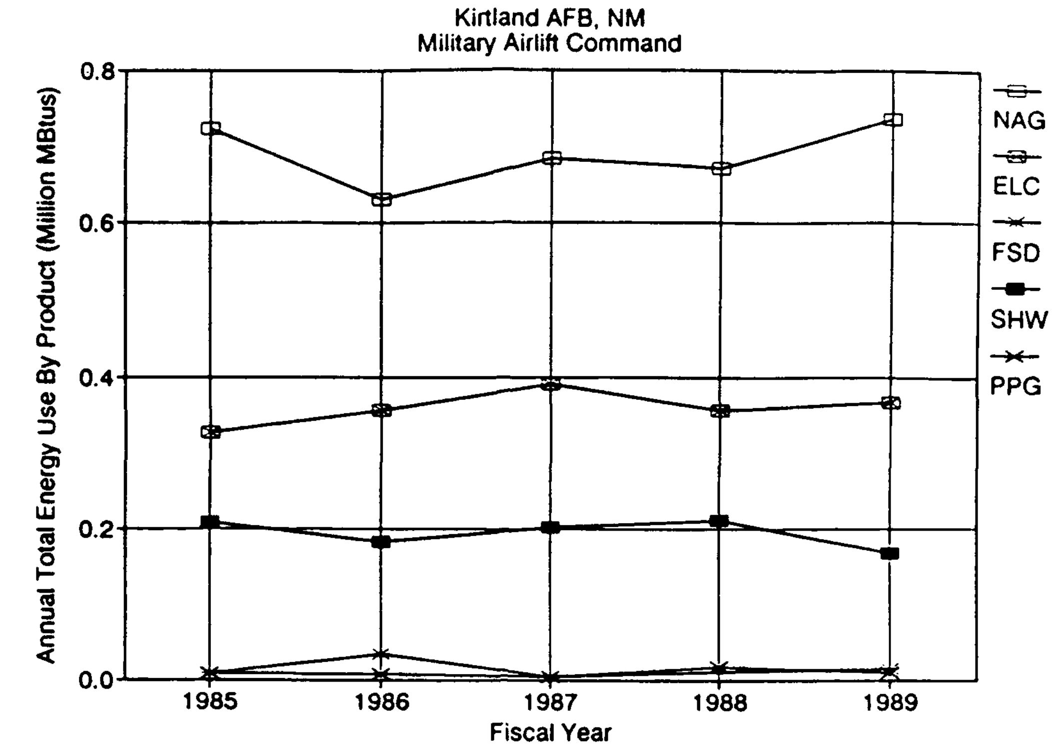

Figure 77. Energy Products Consumed Annually by Kirtland AFB.

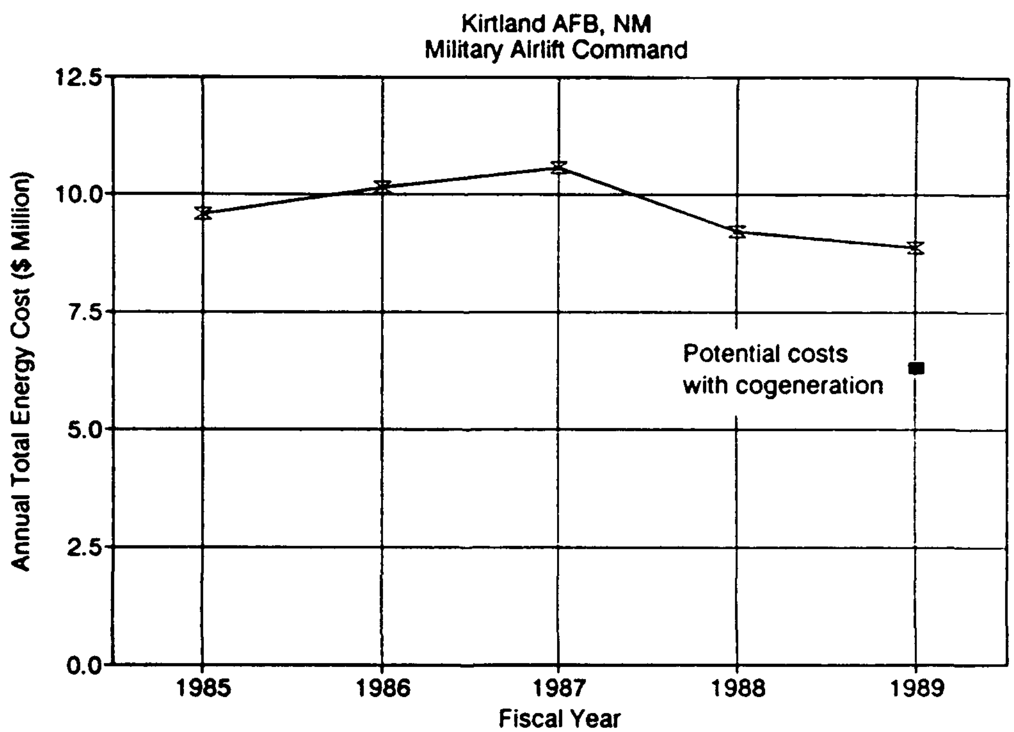

Figure 78. Annual Energy Costs for Kirtland AFB.

Many of the technical and reliability problems associated with cogeneration systems have been overcome; nevertheless, previous efforts to install cogeneration systems at military bases have encountered many nontechnical difficulties. Resistance from local power companies and regulating agencies regarding the establishment of a competing utility have frustrated many attempts (Reference 114). Although, funds for purchasing and installing new cogeneration systems by the military have been difficult to obtain from Congress, recent policy guidelines and legislative initiatives offer renewed hope (Section I). The AF is proceeding with the installation of a gas-fired cogeneration system at McDill AFB, FL.[1]

Resistance from the local power company regarding the McDill AFB cogeneration plant resulted in a ruling by the Florida Public Utilities Commission in favor of the AF, thus establishing a precedent for such cases. Opportunities for third-party financing and the mandate that third-party financing be strongly considered for new power plants on military bases have provided avenues for funding onbase cogeneration systems. However, a thorough understanding and careful wording of third-party financing contracts is essential to ensure the terms are favorable to the AF under all foreseeable circumstances and also that the government is not illegally obligated to specified funding commitments for future years.

At some locations, heat will be the primary commodity with electrical power the byproduct. At other locations the opposite may be true. Research and development in cogeneration for individual housing units is being conducted and should result in increased use on military installations (Reference 115). The Marine Corps has installed cogeneration systems for dining and housing facilities (Reference 116); the Army also has contracted for the installation of a privately-owned cogeneration system (Reference 117).

The cogeneration process is particularly attractive where multiple-generator power plants must be kept constantly in operation to provide high-quality, high-reliability power for critical AF facilities. This trend could be further accelerated for E&S operations because of the congressionally-mandated privatization requirements (Reference 118). The smaller, onbase power generation systems lend themselves more readily to the financial capabilities of the private investor than do large municipal generating plants.

[1]Personal discussion, Mr. Willis Barrow, HQ, TAC/DEMU, USAF, Langley AFB, VA, March 1991.

4. Solar Thermal Systems

A large number of airbases are located in regions with abundant solar insolation (Figure 79). Yet most of these airbases continue to be heated by natural gas or coal and cooled by electrical refrigeration. Several of the airbases use large amounts of process steam, again supplied by fossil fuels. The majority of this total thermal load could be supplied by solar energy. Flat-plate collectors, installed on military family housing units in these areas, could supply most of their domestic hot water needs. Fields of parabolic trough concentrating solar collectors could supply higher temperature hot water or steam for heating airbase facilities during winter months, and steam to operate absorption chillers for cooling in the summer. Some of the process steam could also be supplied by solar systems. Hot water produced by solar during the day could be stored for use at night. In all cases, some fossil-fuel backup capability would be required for cloudy days and, where necessary, to increase the temperatures of solar preheated water or steam. Existing airbase systems can often be modified to connect directly to solar systems. Major conversions to solar energy at airbases with good insolation could reduce consumption of large amounts of fossil fuels and greatly reduce associated costs.

Installation of major solar systems requires large land areas for the solar collector fields but most airbases have sufficient available land to meet this requirement. They also require frequent cleaning, maintenance, and upkeep. This service can readily be provided by either a third-party operator or a maintenance contractor paid for out of the savings in fossil fuel costs.

5. Wind Energy Systems

Many airbases and air stations have abundant wind energy resources (Figure 80). The rapid maturing of large wind energy systems that can provide sizeable quantities of electrical power may provide major opportunities for low-cost, wind-generated electrical power on airbases or nearby federally-owned land. Third party-financed and operated wind farms have the potential of providing large amounts of electrical power to displace higher cost power purchased from utility companies or generated onbase using diesel fuel. A detailed study of each location would be necessary to ensure that sufficient wind resources are indeed available, the economics are really favorable for the AF, and the proposed wind farm operations are compatible with military operations at that airbase.

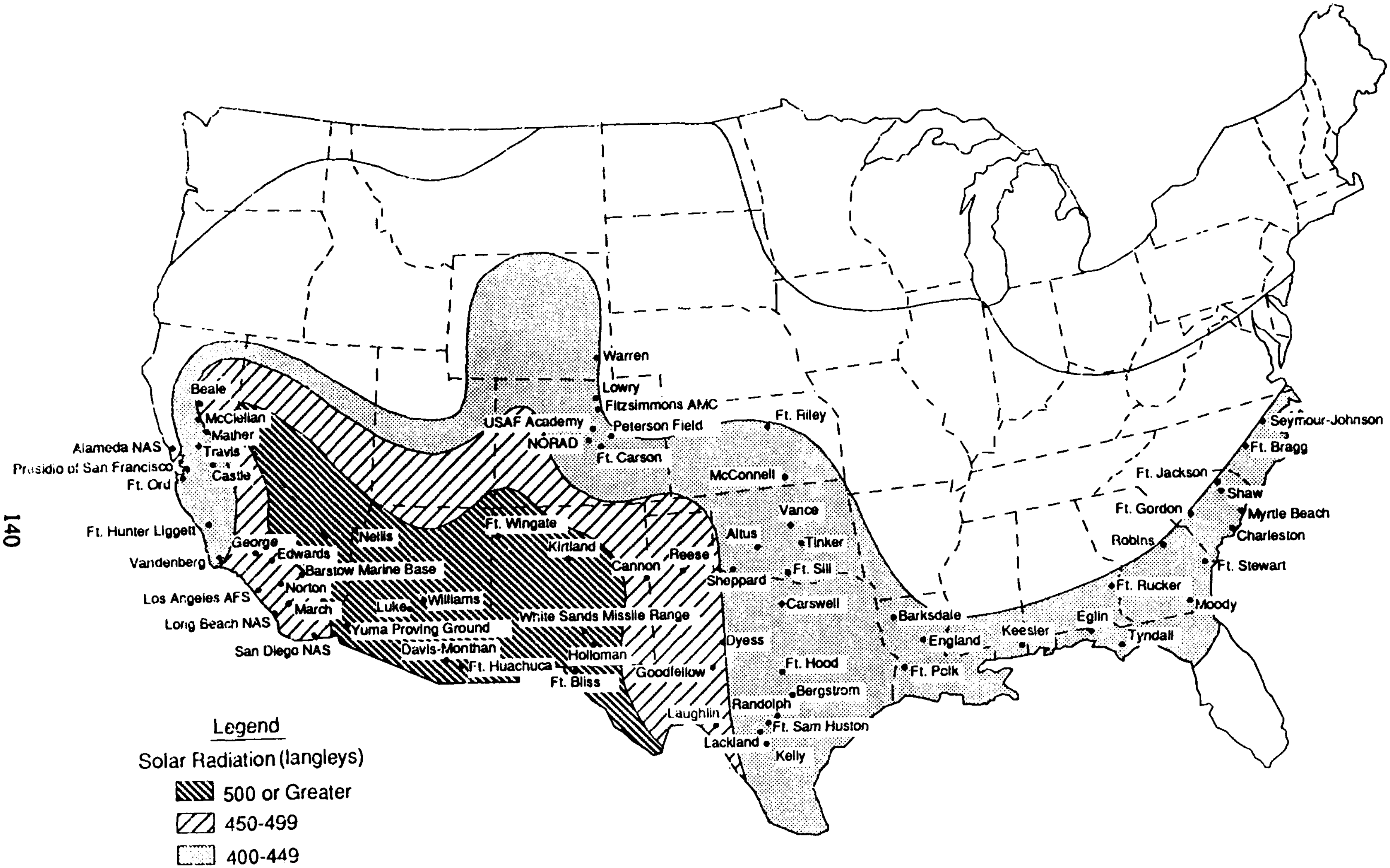

Figure 79. Military Installations Located in Regions with High Levels of Solar Insolation.

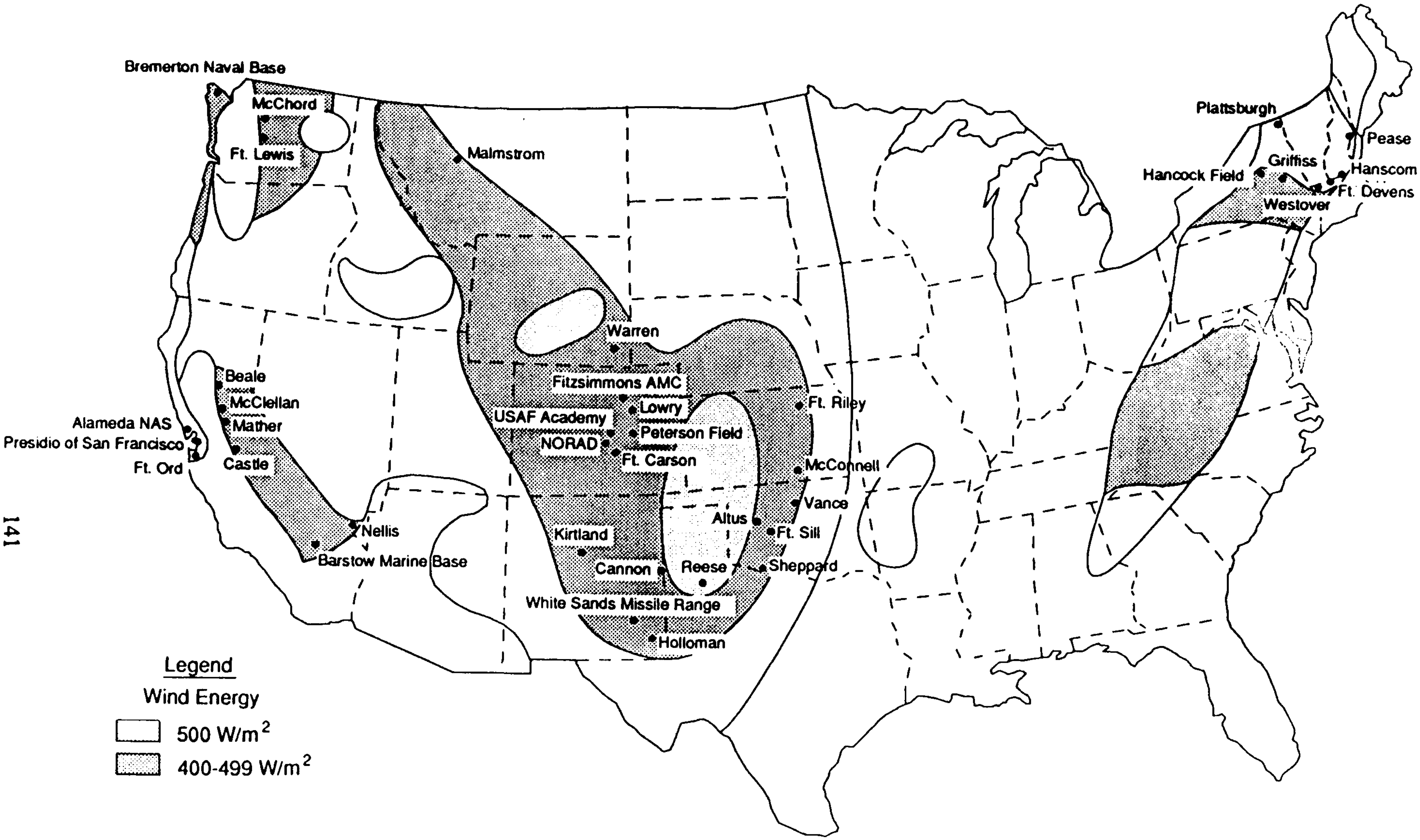

Figure 80. Military Installations Located in Regions with Good Wind Energy.

6. Geothermal Systems

Geothermal power systems can be very workable and a valuable source of energy for military bases. At least one base, the Naval Weapons Center (China Lake, CA) has made good use of its geothermal resources, discovered in 1964 (Reference 119). Many years of struggling to overcome bureaucratic resistance and roadblocks — in the military, the state of California, and the private sector — delayed the project until the mid-1980s. Finally, third-party financing was used to construct two large geothermal, steam-turbine generating plants. Power produced is used first to satisfy the needs of the military base with excess power sold to the local power company. The project is currently producing income of nearly $1 M per day, a portion of which is returned to the Navy, making it a very profitable project for all involved parties.

A map showing military bases located in regions of high geothermal potential in the CONUS is provided in Figure 81 (Reference 120). Nearly all of the military services have conducted studies to identify potential geothermal sources on their bases (References 119 through 121). There are indications of substantial geothermal potential at several military bases. Specifically, a 1978 study accomplished by the Naval Weapons Center (China Lake, CA) for the Air Force Engineering and Services Center (Reference 121) identified nine AF airbases and air stations thought to have significant geothermal potential.

7. Off-Peak Ice Storage

As discussed in Section V, off-peak ice production and storage to reduce air conditioning power costs, is a mature technology. A number of commercial systems that can be easily adapted to existing air-conditioning systems are readily available. A number of AF airbases could greatly reduce refrigerated air-conditioning costs through off-peak ice production and storage. Airbases located in hot humid climates that support large, air-conditioned, people-occupied buildings are prime candidates. Off-peak ice production can be beneficial in headquarters buildings, training class rooms, and large operations buildings. The cost differential between on-peak and off-peak electric power rates is a major factor in determining whether off-peak ice production systems should be installed.

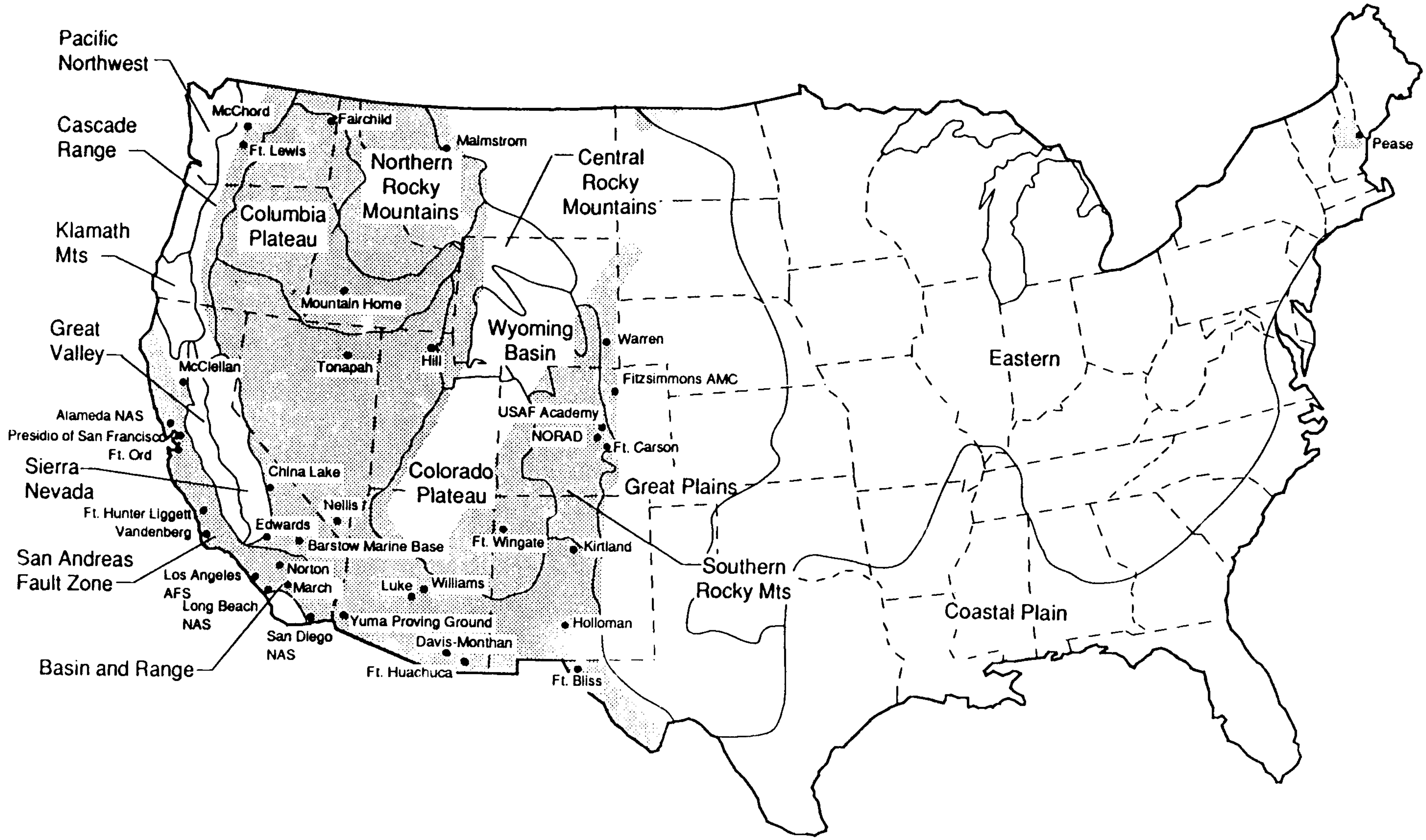

Figure 81. Military Installations Located in Hot Crustal Regions of the CONUS Where Geothermal Activities are Likely.

8. Absorption Cooling

Absorption cooling is another mature technology that can greatly benefit many AF airbases, especially at locations where electric power rates are high, both on-peak and off-peak. The available sources of low-cost thermal energy (solar steam, cogeneration, geothermal, low-cost natural gas, etc.) also suggest the use of absorption cooling. Absorption cooling systems are particularly suitable for large, people-occupied buildings with central air-conditioning systems. Substantial reductions in air-conditioning costs can usually be achieved. In the future, smaller absorption cooling systems, appearing on the commercial market, can be employed to cool smaller airbase buildings, especially where supplies of low-cost natural gas are readily available.

B. MID-TERM TECHNOLOGIES

Several oncoming energy technologies show good potential for meeting projected AF energy needs 5 to 15 years in the future; however, some are related more to increased levels of force projection and mobility basing than to fixed airbases.

1. Solar Photovoltaic Systems

In 1988, DOD in conjunction with DOE, began a 3-year program to expand the use of photovoltaic power systems by the military (Reference 122). The evolutionary advances described in Section VI could significantly change the way in which E&S personnel provide power and heat at many Air Force bases and installations. A much greater use of photovoltaic systems could be mandated in sunny locations, which would require some different skills and training for AF energy personnel.

2. Mobile Photovoltaic Systems

Air Force operations in the future are likely to be more involved with force projection to all parts of the world and operations from remote mobility bases. Also, to ensure survivability of satellite ground link command, control, and communications systems, it will, at times, be necessary for them to disperse into mobility caravans that can deploy and move frequently so as to obscure their location. In each of the above cases, the supply of petroleum fuels for sufficient power generation presents a major logistics problem. Frequent resupply traffic can also compromise location security. An alternative source of electric power, which can be readily transported with the mobile unit and which can provide sufficient amounts of power to greatly reduce the needed supplies of petroleum fuels, is needed.[1] The rapid increase in maturity and efficiency achieved with solar photovoltaic systems over the past several years (Section VI) shows great promise of being able to meet this need, especially in sunny regions. Easily transportable solar photovoltaic arrays could provide substantial amounts of electrical power during daylight hours and charge batteries for use after dark. Although petroleum-fueled generators would still be required for much of the nighttime and cloudy days, the amount of fuel needed could be greatly reduced. Unfortunately, solar photovoltaic arrays in their current stage of development are not well suited for mobile operations and survivability. More R&D in this area is needed.

3. Solar Ice Maker

Dehydration is a significant health problem for military troops deployed in hot climates. The ready availability of cold drinks and ice can greatly alleviate that problem. The current method of keeping drinking fluids cold is with conventional vapor-phase refrigeration systems powered by diesel electric generators. An alternative approach may be available through a military version of the solar absorption ice maker (ISAAC) described in Section VI. In regions where adequate direct solar insolation is available, such machines would make ice during the night for use the following day. They would require reconfiguration twice each day, but would produce ice using only fresh water (for the ice) and sunlight. The military version would be designed with low cubage for shipping, low mobility requirements, toughness and durability, and ease of operation.

4. Hybrid Solar/Thermophotovoltaic Systems

The hybrid solar/thermophotovoltaic (HSTPV) system concept described in Section VI may have significant potential for development for power systems that could serve both mobility bases (such as in the recent Gulf war) and mobile caravans for satellite data transmission (Reference 123). The concept consists of a thermophotovoltaic (TPV) system that would operate on any standard petroleum fuel available at the mobility base (diesel, JP-4, JP-8, etc.) The system would be designed so that, during daylight hours, it could be easily and rapidly reconfigured to move the photovoltaic cells up and into the sunlight where they would be illuminated by concentrating solar collectors (probably parabolic dishes or Fresnell lenses). Thus, during daylight hours the system would produce only electricity and consume no fuel. At sunset, the system would be restored to the TPV configuration where it would produce both electricity and heat; the

[1]Personal communication, military personnel from Air Force Space Command, May 1990.

heat would be used to provide domestic hot water and meet other needs. The system could be either manually reconfigured twice each day or controlled by sunlight sensors to do so automatically. With this system, mobility base fuel consumption could be reduced approximately in half. No such HSTPV system currently exists. Substantial R&D work would be required. However, the concept appears to be technically very feasible and operationally attractive.[1]

5. Fuel Cells and Fuel-Cell Cogeneration

Every airbase offers many potential opportunities for using fuel cells and fuel-cell cogeneration to help reduce energy consumption, lower energy-related costs, and reduce pollution. Fuel-cell cogeneration systems can be employed at many airbase locations to provide both electrical power and steam. The steam can be used for industrial process heat, for facility heating in the winter, for absorption cooling in the summer, and for domestic hot water year round. Fuel cells can also be used as backup generators to provide power when other systems fail or must be shut down for repair.

For mobility operations the AF has a continuing need for reliable, compact light-weight, air transportable electric power generating units that can operate quietly on a wide range of fuels. Fuel-cell power generating systems can meet this need (Reference 124). A 40-kW solid oxide fuel cell generator is sufficiently light to be carried by one person.

C. FAR-TERM TECHNOLOGIES

1. Hydrogen Fuels

A number of ongoing R&D and system development activities reveal trends that suggest a much greater AF involvement with hydrogen fuels in the next 15 to 30 years. Such activities as the development of the National Aerospace Plane (NASP), the conceptual development of NASP derivative vehicles (NDVs) ongoing at Aeronautical Systems Division, and the joint NASA/Air Force plans for developing a hydrogen-fueled, heavy-lift launch vehicle for space missions are clear indicators of this trend (Section V). The NASP project will lead to remarkable new ways for man to travel into space (Reference 125), and hydrogen fuels are the key to that concept (Reference 126). New facilities that include hydrogen production, storage, and

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[1]Personal communication, Dr. Paul A. Basore, Photovoltaic Technology Research Division, Sandia National Laboratory, Albuquerque, NM, March 1991.

transportation equipment must be built by the AF so that the X-30 NASP can be tested (Reference 127). The development and use of the new National Launch System will require the construction and use of hydrogen fuel systems at Air Force space launch sites. Current environmental problems related to the frequent launch of chemical-fuel rockets are already urging the rapid transition to environmentally benign hydrogen fuels.[1]

Once the AF becomes extensively involved in the use of hydrogen fuels for flight vehicles, it is a logical step to the use of hydrogen for surface vehicles and other airbase energy needs. The situation is similar to the current ongoing efforts to be able to use a single fuel (JP-8) for all airbase energy needs at certain locations.

2. High-Temperature Superconducting Electrical Systems

The ongoing R&D efforts in high-temperature superconducting materials, discussed in Section VI, will likely, in 15 to 30 years, lead to a variety of higher performance electrical and electronic devices that could vastly improve electrical systems on AF airbases. A quantum reduction in the electrical resistance of transmissions lines, transformers, and other onbase electrical equipment could substantially reduce consumption and cost of airbase electrical power. The constant running of numerous electrical motors accounts for a large portion of airbase electrical power consumption, which could be lowered by the use of high-temperature, superconducting electrical motors, with associated reductions in costs.

Superconducting magnetic energy storage systems could be used to store low-cost, off-peak electrical power for use during high-cost, peak-load periods. They also could be used to store electricity for powering critical systems during times of emergency, thus enhancing airbase energy security.

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[1]Personal communication, personnel from Air Force Space Systems Division (SSD/DE) regarding environmental concerns associated with the launch of chemical rockets from Vandenburg AFB, CA, 6 Nov 1991.

SECTION VIII
RECOMMENDED R&D EFFORTS

A. EFFORTS TO MEET NEAR-TERM NEEDS

1. Airbase Energy System Analyses and Energy Project Development

In the near term, the facility/utility energy needs of the Air Force can best be served by a series of energy system analyses and energy project development activities in direct support of MAJCOMS and individual airbases to help ensure that when existing airbase energy systems must be modified, replaced, or added to because of age, wear, damage, or insufficient capacity, the energy system approach employed is the most energy-conserving, cost-beneficial, and environmentally compatible approach available. Detailed engineering analyses should be performed to ensure the technical soundness of the proposed project; life-cycle cost analyses must be accomplished to include the projected future true cost of energy products, capital and installation costs with and without third-party financing, projected environmental compliance and cleanup costs, etc.; and technical, economic, and environmental consulting and advisory services should be provided to help the airbases and MAJCOMs select the best possible approaches for improving their energy posture for now and in the future. Only mature technologies should be addressed under this area of endeavor. Some specific airbase energy areas where the above analysis and project development services can be of immediate benefit are listed below. Each has been discussed previously in Sections VI and VII.

For each of the energy technology areas listed it is recommended that assistance be provided to MAJCOMS and individual airbases to accomplish the following:

a. Determine whether the circumstances at the airbase are favorable for the proposed energy system.
b. Perform preliminary technical and economic analyses to determine whether the proposed energy system will indeed provide sufficient benefits for the Air Force.
c. Provide assistance in formulating projects to acquire, install, and operate the proposed energy systems.

d. Recommend the following energy systems be considered.

Energy-Conserving Lighting Systems: Determine where airbase lighting systems are being unnecessarily activated, where more energy-effective lighting systems could be installed, and where sensor controlled lights are needed.

Onbase Cogeneration Systems: For a variety of valid reasons the AF finds it necessary, each year, to change, add to, or completely replace, a substantial number of major airbase energy systems (steam plants, boilers, electrical substations, refrigeration systems, etc.). The normal approach is to use traditional systems which, in many cases, are not as energy-conservative or cost-beneficial as cogeneration systems. Newer, more energy-effective system approaches are usually not considered for a variety of reasons. Determine where the necessary circumstances for successful cogeneration projects exist and initiate projects to acquire, install, and operate such systems.

Off-Peak Energy Storage Systems: Determine where substantial cost savings can be achieved by installing off-peak ice production and storage systems. Initiate necessary projects to acquire, install, and operate such systems.

Thermally-Operated Absorption Cooling Systems: Determine where thermally-operated absorption cooling systems can be installed to replace electric-powered, vapor-phase refrigeration systems and thus reduce electricity consumption and lower cooling costs. Energy for such systems could be supplied by cogeneration systems, natural gas, or steam from solar collectors. Initiate projects to acquire, install, and operate absorption cooling systems where technically and economically justified.

Solar Thermal Systems: Determine where solar insolation is sufficient to provide abundant, low-cost thermal energy and displace other more costly energy products. Initiate projects to employ solar thermal systems where appropriate.

Wind Power tems: Determine airbase loc 'ions where wind power resources are ficient to provide substantia iantities of low-cost electric power. Initia.. projects to utilize this renewable resource.

2. Mobile Solar Photovoltaic Power System

The need for a mobile solar photovoltaic (PV) power system has been explained (Section VII). A project to develop, test, and evaluate such a system is recommended as a near-term development effort. A solar photovoltaic array of sufficient size to provide the needed electric power during daylight hours, thus making it unnecessary to operate diesel generators during this period, should be considered. Such a system should greatly reduce quantities of fuels required for diesel generators. The solar PV array must be reliable, durable, lightweight, and compact when in its stored configuration, and very easy to erect, dismantle, and store. The solar PV system should have a high degree of survivability both to natural threats (lightning, wind storms, etc.) and to enemy threats (bullet penetration, bomb blast, fragmentation, EMP, etc.).

3. Fuel-Cell Cogeneration Systems

As explained earlier in Section VII, fuel cell power generation systems offer some significant advantages for use both at fixed airbases and for mobility operations. A project to develop a family of fuel-cell power generators and fuel-cell cogeneration systems should be initiated in the near future. Adapting DOE-developed prototypes to meet AF needs may be the most direct approac Again, such systems must be reliable, durable, survivable, and suitable for military opera is. The systems should be quiet, have a high conversion efficiency with low pollution, and e able to use multiple fuels (liquid or gas). Waste heat should be captured for domestic uses. The system should be designed to support both fixed and mobile airbases.

B. EFFORTS TO MEET MID-TERM NEEDS

As suggested in Sections VI and VII, several new energy technologies show potential for significant contributions to AF energy needs 5 to 15 years in the future and warrant AF supported R&D efforts. Some relate more to force projection and mobility basing needs than to fixed airbase installations.

1. Small LiBr Absorption Cooling Systems

Small, thermally operated LiBr absorption cooling systems could be used effectively for a variety of airbase applications, thus saving substantial cooling costs. A project to develop appropriate versions of these systems within the next few years is recommended. The systems should be inexpensive to operate, durable, highly reliable, and have low maintenance costs.

2. Solar Ice-Making Systems

A military version of the solar ice maker described in Sections VI and VII is recommended for development in the next few years. The system should be durable, easily transportable, highly reliable, and simple to operate by personnel with minimum training.

3. Hybrid Solar/Thermal Photovoltaic Power Systems

A very significant R&D effort to develop hybrid solar/thermal photovoltaic power systems for airbase mobility operations is recommended to be initiated within the next five years. Described in Sections VI and VII, such a system could completely replace diesel generators, require less petroleum fuel, and provide thermal energy for airbase needs. Development efforts should be focused on high efficiency, reliability, durability, ease of transportation, and minimum O&M difficulties.

C. EFFORTS TO MEET FAR-TERM NEEDS

In the far term, more fundamental (basic research) types of technology related to airbase systems anticipated to exist 15 or more years in the future are appropriate. Although there is far less certainty regarding airbase energy system needs at that time, some topics can nevertheless be suggested.

1. Hydrogen Fuels for Multiple Airbase Energy Use

In Sections VI and VII a case was made for the eventual conversion to the use of large amounts of hydrogen fuels for a multitude of purposes throughout our society. It has also been argued that because of the necessity for using hydrogen fuels for aerospace vehicle propulsion, the AF is likely to be on the forefront of this transformation process. Many problems relating to the use of hydrogen fuels still exist and will need to be solved, especially when envisioned as a fuel for common airbase use, before that transition can occur. Thus, a case can be made for investing some amount of long-range research funds on hydrogen technologies.

A first concern is the basic cost of producing hydrogen, especially by processes that do not consume fossil fuels or create additional environmental pollutants. As stated earlier, many processes for producing hydrogen from a variety of feedstocks have already been developed (Reference 90). Yet, further improvements on these processes, or the development of entirely new processes for the production of hydrogen (especially from water) may be possible. The great benefits that could accrue to the AF and to our society from a low-cost approach to the production of hydrogen from water makes this an attractive area for future R&D investment.

A second concern is related to the more extensive use of hydrogen for many applications and at many locations on nearly every airbase. The assumption is that ordinary workers, not specially trained in handling hydrogen will be involved in these hydrogen-handling activities. It will be necessary then to have self-sealing, easy to operate, hydrogen-pumping equipment which the average airman can operate without extensive special training. Hydrogen handling equipment (pumps, valves, meters, nozzles, hose connection devices, etc.) that can be used by minimally trained personnel, in much the same manner as airbase refueling systems for airplanes, motor vehicles, and facility energy systems, is needed. R&D efforts to develop these capabilities are recommended to begin within the next 10 years.

2. High-Temperature, Superconducting Electrical Systems

Within the next 10 years, high-temperature, superconducting materials and components should begin to appear on the commercial market. A R&D program to begin adapting such materials and components to improve airbase energy systems is recommended to be initiated within the same time period. The program, focused on the unique requirement associated with military operations, should be formulated to take maximum advantage of developments by other government laboratories and private industries.

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APPENDIX A

LISTING OF USAF MAJCOMS AND AIRBASES

APPENDIX A

LISTIN[illegible] USAF MAJCOMS AND AIRBASES

Alaskan Air Command (AAC)

FP5010	Cape Lisburne AFS
FP5011	Cape Newenham AFS
FP5014	Cape Romanzof AFS
FP5018	Cold Bay AFS
FP5004	Eielson AFB
RP5004	Eielson AFB
FP5000	Elmendorf AFB
RP5000	Elmendorf AFB
FP5016	Fort Yukon
FP5060	Galena ARPT
FP5013	Indian Mtn AFS
FP5007	King Salmon ARPT
FP5012	Kotzebue AFS
FY8785	Murphy Dome AFS
FP5040	Shemya AFB
FP5020	Sparrevohn AFS
FP5015	Tatalina AFS
FP5017	Tin City AFS

Air Force Logistics Command (AFLC)

FP2027	Hill AFB, UT
RP2027	Hill AFB
FP2059	Kelly AFB, TX
RP2059	Kelly AFB
RP2049	McCellan AFB
FP2049	McCellan AFB, CA
FP2006	Newark AFS, NJ
RP2006	Newark AFS
FP2065	Robins AFB, GA
RP2065	Robins AFB
FP2039	Tinker AFB, OK
RP2039	Tinker AFB
FP2300	Wright-Patterson AFB, OH
RP2300	Wright-Patterson AFB

Air Force Reserves (AFRES)

FP6618	Chicago O'Hare IAP, IL
FP6703	Dobbins AFB, GA
FP6605	Gen Billy Mitchell Field, WI
FP6633	Min-St Paul IAP, MN
FP6670	Niagara Falls IAP, NY
FP6712	Pittsburgh IAP, PA
FP6606	Westover AFB, MA
FP6637	Willow Grove, PA
FP6656	Youngstown MAP, OH

Air Force Systems Command

EY1525	Anderson Peak
EY7483	Arnold AFS, TN
RY7493	Arnold AFS, TN
RG2957	Brooks AFB, TX
FG2857	Brooks AFB, TX
RP2805	Edwards AFB, CA
FP2805	Edwards AFB, CA
FP2835	Hanscom AFB, MA
RP2835	Hanscom AFB, MA
RY7396	Los Angeles AFB, CA
EY7396	Los Angeles AFS, CA
EY9889	Molokai AFS, HI
FY8049	NH Satellite TS
FP2829	Patrick AFB, FL
EY7765	Pillar Point AFS, CA
EY9887	Santa Ynez Peak TS
FY7895	Sunnyvale AFB, CA

Air Force Washington District (AFWD)

FP4200	Bolling AFB, DC
RP4200	Bolling AFB, DC

Air National Guard (ANG)

FP6011	Alabama ANG NO. 1
FP6012	Alabama ANG NO. 2
FP6520	Alaska ANG
FP6021	Arizona ANG
FB6031	Arkansas ANG
FP6044	California ANG
FP6061	Colorado ANG
FP6071	Connecticut ANG
FP6081	Delaware ANG
FP6091	Florida ANG
FG6101	Georgia ANG
FP6112	Idaho ANG
FP6122	Illinois ANG
FP6131	Indiana ANG
FP6141	Iowa ANG
FP6152	Kansas ANG
FP6161	Kentucky ANG
RP2560	Kingsley Fld OR
FP2560	Kingsley Fld OR
FY8228	Louisiana ANG
FP6181	Maine ANG
FP6191	Maryland ANG
FP6201	Massachusetts ANG No. 1
FP6202	Massachusetts ANG No. 2
FP6221	Michigan ANG No. 1
FP6222	Michigan ANG No. 2
FG6231	Minnesota ANG
FP6241	Mississippi ANG
FP6251	Missouri ANG
FP6261	Montana ANG
FP6271	Nebraska ANG
FP6281	Nevada ANG
FG6303	New Jersey ANG
FG6321	New York ANG
FP6331	North Carolina ANG
FP6341	North Dakota ANG
FP6352	Ohio ANG NO. 1
FP6356	Ohio ANG NO. 2
FG6563	Oklahoma ANG
FP6371	Oregon ANG
FG6381	Pennsylvania ANG
FP6540	Puerto Rico ANG
FP6391	Rhode Island ANG
FP6401	South Carolina ANG

ANG (Continued)

FP6411	South Dakota ANG
FP6421	Tennessee ANG
FP6431	Texas ANG No. 1
FP6433	Texas ANG No. 2
FP6441	Utah ANG
FP6451	Vermont ANG
FP6461	Virginia ANG
FP6471	Washington ANG
FP6481	West Virginia ANG
FP6492	Wisconsin ANG
FP6501	Wyoming ANG

Air Training Command (ATC)

FP3018	Chanute AFB, IL
RP3018	Chanute AFB, IL
FP3022	Columbus AFB, MS
RP3022	Columbus AFB, MS
FP3030	Goodfellow AFB, TX
RP3030	Goodfellow AFB, TX
FG4444	Gunter AFB, AL
RG4444	Gunter AFB, AL
FB3010	Keesler AFB, MS
RB3010	Keesler AFB, MS
FB3047	Lackland AFB, TX
FP3099	Laughlin AFB, TX
RP3099	Laughlin AFB, TX
FB3059	Lowry AFB, CO
RB3059	Lowry AFB, CO
FP3067	Mather AFB, CA
RP3067	Mather AFB, CA
FP3300	Maxwell AFB, AL
RP3300	Maxwell AFB, AL
FP3089	Randolph AFB, TX
RP3089	Randolph AFB, TX
FP3060	Reese AFB, TX
RP3060	Reese AFB, TX
FP3020	Sheppard AFB, TX
RP3020	Sheppard AFB, TX
FP3029	Vance AFB, OK
RP3029	Vance AFB, OK
FP3044	Williams AFB, AZ
RP3044	Williams AFB, AZ

Air University (AU)

FG4444	Gunter AFB
RG4444	Gunter AFB
FP3300	Maxwell AFB
RP3300	Maxwell AFB

Miltary Airlift Command (MAC)

RP4419	Altus AFB, OK
FP4419	Altus AFB, OK
FP4425	Andrews AFB, MD
RP4425	Andrews AFB, MD
RP4418	Charleston AFB, SC
FP4418	Charleston AFB, SC
RP4497	Dover AFB, DE
FP4497	Dover AFB, DE
FY7994	Gibbsboro AFS, NJ
RY7994	Gibbsboro AFS, NJ
RY9114	High Wycombe AFS, UK
RY9114	High Wycombe AFS, UK
RP4417	Hurlburt Field, FL
FP4417	Hurlburt Field, FL
RP4469	Kirtland AFB, NM
FP4469	Kirtland AFB, NM
RP4486	Lajes Field, Azores
FP4486	Lajes Field, Azores
FP4460	Little Rock AFB, AR
RP4460	Little Rock AFB, AR
RY9755	Makah AFS
FY9755	Makah AFS
FP4479	McChord AFB, WA
RP4479	McChord AFB, WA
FP4484	McGuire AFB, NJ
RP4484	McGuire AFB, NJ
RP4448	Norton AFB, CA
FP4448	Norton AFB, CA
RY9749	Point Arean AFS
FY9749	Point Arean AFS
RP4488	Pope AFB, NC
FP4488	Pope AFB, NC
FP4420	Rhein-Main AB, Germany
RP4420	Rhein-Main AB, Germany
FP4407	Scott AFB, IL
RP4407	Scott AFB, IL
RP4427	Travis AFB, CA
FP4427	Travis AFB, CA

Pacific Air Forces (PACAF)

RP4624	Andersen AFB, Guam
FP4624	Andersen AFB, Guam
RP5250	Clark AB, Philippines
FP5250	Clark AB, Philippines
FP5260	Hickam AFB, HI
RP5260	Hickam AFB, HI
RB5250	John Hay AB, Philippines
FB5250	John Hay AB, Philippines
FP5270	Kadena AB, Japan
RP5270	Kadena AB, Japan
RP5284	Kunsan AB, S. Korea
FB5284	Kwangju AB, S. Korea
RB5205	Misawa AB, Japan
FB5205	Misawa AB, Japan
FP5294	Osan AB, S. Korea
RP5294	Osan AB, S. Korea
FB5294	Suwon AB, S. Korea
FG5294	Taegu AB, S. Korea
FG5250	Wallace AS, Philippines
FP5209	Yokota AB, Japan
RP5209	Yokota AB, Japan

Strategic Air Command (SAC)

RP4608	Barksdale AFB, LA
FP4608	Barksdale AFB, LA
RP4686	Beale AFB, CA
FP4686	Beale AFB, CA
FP4689	Carswell AFB, TX
RP4689	Carswell AFB, TX
FP4672	Castle AFB, CA
RP4672	Castle AFB, CA
RP4661	Dyess AFB, TX
RP4661	Dyess AFB, TX
RP4634	Eaker AFB, AR
FP4634	Eaker AFB, AR
FP4690	Ellsworth AFB, SD
RP4690	Ellsworth AFB, SD
RP4613	Warren AFB, WY
FP4613	Warren AFB, WY
RB4620	Fairchild AFB, WA
FB4620	Fairchild AFB, WA
RB4659	Grand Forks AFB, ND
FB4659	Grand Forks AFB, ND

SAC (continued)

RP4616	Griffiss AFB, NY
FP4616	Griffiss AFB, NY
RP4654	Grissom AFB, IN
FP4654	Grissom AFB, IN
RP6324	Hancock Field, NY
FP6324	Hancock Field, NY
FB4515	Sawyer AFB, MI
RB4515	Sawyer AFB, MI
RB4678	Loring AFB, ME
FB4678	Loring AFB, ME
RP4626	Malmstrom AFB, MT
FP4626	Malmstrom AFB, MT
FP4664	March AFB, CA
RP4664	March AFB, CA
RP4621	McConnell AFB, KS
FP4621	McConnell AFB, KS
FP4528	Minot AFB, ND
RP4528	Minot AFB, ND
FP4600	Offutt AFB, NE
RP4600	Offutt AFB, NE
RP4623	Pease AFB, NH
FP4623	Pease AFB, NH
RP4615	Plattsburgh AFB, NY
FP4615	Plattsburgh AFB, NY
FB4610	Vandenberg AFB, CA
RB4610	Vandenberg AFB, CA
FP4625	Whiteman AFB, MO
RP4625	Whiteman AFB, MO
RP4585	Wurtsmith AFB, MI
FP4585	Wurtsmith AFB, MI

Space Command

FB2510	Cheyenne Mt. AFB, CO
EY7676	Clear AFS, AK
FY1623	Falcon AFB, CO
FY7743	New Boston AFS, NH
FY7311	Onizuka AFB, CA
RP4500	Peterson AFB, CO
FP4500	Peterson AFB, CO
FP2547	Sondrestrom AB, Greenland
FP2573	Thule AB, Greenland
RP4575	Woomera AS, Australia
FP4575	Woomera AS, Australia

Tactical Air Command (TAC)

FP4857	Bergstrom AFB, TX
RP4857	Bergstrom AFB, TX
RP4855	Cannon AFB, NM
FP4855	Cannon AFB, NM
FP4877	Davis-Monthan AFB, AZ
RP4877	Davis-Monthan AFB, AZ
EY2700	Dewline System, AK
RP4805	England AFB, LA
FP4805	England AFB, LA
RP4812	George AFB, CA
FP4812	George AFB, CA
RP4801	Holloman AFB, NM
FP4801	Holloman AFB, NM
FP4829	Homestead AFB, FL
RP4829	Homestead AFB, FL
RP4810	Howard AFB, Panama
FP4810	Howard AFB, Panama
FP4800	Langley AFB, VA
RP4800	Langley AFB, VA
RP4887	Luke AFB, AZ
FP4887	Luke AFB, AZ
FP4814	MacDill AFB, FL
RP4814	MacDill AFB, FL
FP4830	Moody AFB, GA
RP4830	Moody AFB, GA
RP4897	Mountain Home AFB, ID
FP4897	Mountain Home AFB, ID
FP4806	Myrtle Beach AFB, SC
RP4806	Myrtle Beach AFB, SC
RP4852	Nellis AFB, NV
FP4852	Nellis AFB, NV
FP4809	Seymour Johnson AFB, NC
RP4809	Seymour Johnson AFB, NC
FP4803	Shaw AFB, SC
RP4803	Shaw AFB, SC
FP2586	Tyndall AFB, FL
RP2586	Tyndall AFB, FL

United States Air Force Academy (USAFA)

RB7000	USAF Academy, CO
FB7000	USAF Academy, CO

United States Air Forces In Europe (USAFE)

FP5693	Ankara AS, Turkey
RP5693	Ankara AS, Turkey
RP5682	Aviano AB, Italy
FP5682	Aviano AB, Italy
FP5644	RAF Bentwaters-Woodbridge, United Kingdom
RP5644	RAF Bentwaters-Woodbridge, United Kingdom
FP5606	Bitburg AB, Germany
RP5606	Bitburg AB, Germany
FP5541	Comiso AS, Italy
FP5696	Pirinclik AS, Turkey
RP5560	RAF Fairford, United Kingdom
FP5560	RAF Fairford, United Kingdom
FP5630	Florennes AB, Belgium
RP5630	Florennes AB, Belgium
RP5620	Hahn AB, Germany
FP5620	Hahn AB, Germany
FB5687	Hellenikon AB, Greece
RB5687	Hellenikon AB, Greece
FY9114	High Wycombe AFS, United Kingdom
RP5685	Incirlik AB, Turkey
FP5685	Incirlik AB, Turkey
FG5699	Iraklion AS, Crete
RG5699	Iraklion AS, Crete
RB5531	Izmir AS, Turkey
FB5531	Izmir AS, Turkey
FP5575	Moron AB, Spain
RP5575	Moron AB, Spain
FP5643	RAF Alconbury, United Kingdom
RP5643	RAF Alconbury, United Kingdom
FG5650	RAF Chicksands, United Kingdom
RG5650	RAF Chicksands, United Kingdom
FP5537	RAF Greenham Common, United Kingdom
RP5537	RAF Greenham Common, United Kingdom
FB5587	RAF Lakenheath, United Kingdom
RB5587	RAF Lakenheath, United Kingdom
RP5518	RAF Mildenhall, United Kingdom
FP5518	RAF Mildenhall, United Kingdom
FG5553	RAF Sculthorpe, United Kingdom
RG5553	RAF Sculthorpe, United Kingdom
FB5537	RAF Upper Heyford, United Kingdom
RB5537	RAF Upper Heyford, United Kingdom
FP5612	Ramstein AFB, Germany
RP5612	Ramstein AFB, Germany
FG5517	San Vito AS, Italy
RG5517	San Vito AS, Italy
FP5623	Sembach AB, Germany
RP5623	Sembach AB, Germany
FP5688	Soesterberg AB, Netherlands
RP5688	Soesterberg AB, Netherlands
FB5621	Spangdahlem AB, Germany
RB5621	Spangdahlem AB, Germany
FB5622	Tempelhof Central AP, Germany
RB5622	Tempelhof Central AP, Germany
FX5585	Torrejon AB, Spain
RX5585	Torrejon AB, Spain
FB5643	RAF Wethersfield, United Kingdom
RB5643	RAF Wethersfield, United Kingdom
FP5571	Zaragoza AB, Spain
RP5571	Zaragoza AB, Spain
FP5529	Zweibrucken AB, Germany
RP5529	Zweibrucken AB, Germany

APPENDIX B

COMPUTATIONAL STEPS IN CREATING DATA CHARTS FROM DEIS II DATABASE

APPENDIX B

STEPS IN CREATING DATA CHARTS FROM DEIS II DATABASE

I. TRANSFERRING DATA FROM HARRIS (UNIFY) TO PC FORMAT.

A. Logon to Harris

B. Logon to Unify

C. Create Four File Types
   1. Select Report Type
   2. Enter DODAAC(s)
   3. Create Files

D. Transfer Files to PC via Kermit

II. CREATING SOURCE FILES

A. Copy ASCII files to D:*COM**COMS*\ subdirectory

B. Change default directory to above

C. Open blank worksheet (New window)

D. Import Square Footage file *.SFT

E. Save as *COM*SQFT.WQ1 and leave open

F Open blank worksheet (New window)

G Import ASCII source data files
(Comma separated variable) *.BTU, *.DEG and *.CST

H. Format data for source files

See III. FORMATTING SOURCE FILES

...Repeat steps F - H for Usage, Degree Day and Cost tables for each DODAAC in Command

III. FORMATTING SOURCE FILES

All the Source files (Usage, Degree Day and Cost) are created from ASCII files which are imported into blank spreadsheets. These source files need to be formatted so that other files can access the data in a consistent manner. The steps used to format source files vary for each kind of data and are specified on this page.

Usage Data = *.BTU

1. Correct spelling of Base name and Command
2. Macro does the following:
   Inserts or deletes columns or rows so that
   D4 = *DODAAC*, D5 = Base name and D6 = Command
   Inserts Estimated Marker column
   Inserts Fiscal Year Total block
   Inserts Totals column
   E12 = First data point Fiscal Year Totals
   E20 = First data point (Converted Values)
   Inserts Labels for SQFT
3. Copy Fiscal Year data from SQFT data file for *DODAAC* to (G2..H7)
4. Save file as *DODAAC*U1.WQ1
5. Save and close file

Degree Day Data = *.DEG

1. Macro does the following:
   Inserts or delete columns or rows so that
   E12 = First data point Fiscal Year Totals
   E20 = First Cooling data point
   Inserts Estimated Marker column
   Inserts Fiscal Year Total block
2. Save file as *DODAAC*D1.WQ1
3. Save and close file

Cost Data = *.CST

1. Macro does the following:
   Inserts or deletes columns or rows so that
   E12 = First data point Fiscal Year Totals
   E20 = First Cost data point
   Insert Estimated Marker Row
   Insert Fiscal Year Total Block
   Insert Totals Row
2. Save file as *DODAAC*C1.WQ1
3. Save and close file

IV. CREATING TOTAL FILES

A. Chan :efault directory to D:*COM*\

B. Copy ATOTALS.WQ1 (Totals Template) to above directory

C. Open ATOTALS.WQ1 Press N for NONE (No links)

D. Macro does the following:
Requests *DODAAC*, Updates links to Source files:
*DODAAC*U1.WQ1, *DODAAC*D1.WQ1 and *DODAAC*C1.WQ1
Saves the Totals file as *DODAAC*T1.WQ1

E. Print totals for review

F. Close and save Total file

... **Repeat steps C - F for all DODAACS in Command**

V. CREATING COMMAND TOTAL FILE

A. Copy ACOMTOT.WQ1 (Command Total Template) to D:*COM*\directory

B. Open ACOMTOT.WQ1
1. Enter Command name in C2 and location in C3
2. Enter DODAACs in (F2..AD2)
Enter Base Names in (F3..AD3)
3. Place cursor just below Base Name (Row 4)
4. Link Total tables with Macro

... **Repeat 3 & 4 for each DODAAC in Command**

VI. DETERMINING SCALING AND CHART VALUES

A. Print out Command Totals for review.
These figures are used to decide maximum and scaling requirements for the charts. They also indicate which energy products are used in the Command. Review Command Totals for correctness, believability and to annotate estimated data.

B. Save As *COM*TOTL.WQ1

VII. CREATING A NEW COMMAND GRAPH TEMPLATE

A. Copy AGRAPH.WQ1 or AGRAPHES.WQ1 (estimated) Template to D:\COM\AGRAPH.WQ1

B. Open AGRAPH WQ1 Press N for NONE (Nolinks)

C. Change link to first DODAAC in Command

D. Open each chart EUA# 1,2,3,4 and 6
(5 uses it's own default scaling.)

E. Modify the scaling values for each of these charts to reflect the range for the whole Command. The best values can be derived by studying the printed Command Totals.

F. Print each chart to verify scaling values.

G. Save new chart values

VII. PRINTING CHARTS FROM TOTAL FILES

A. Copy AGRAPH.WQ1 (Graph 1-6 Template) to D:\COM\ directory

B. Open AGRAPH.WQ1. Press N for NONE. (No Links)

C. Change links to differents source total file.

D. Modify ranges for EUA #5.
(EUA #5 needs human intervention as it is impossible to predict which products will be used in advance. The Total sheets will show which products were used and need to be plotted. The ranges are already named.) It may also be necessary to modify the scaling values for each chart. The best values can be derived by studying the printed Command Totals. Estimated values may need to be annotated.

E. Print Base Charts. (EUA# 1-6)

F. Close and Save as *DODAAC*G1.WQ1.

... **Repeat Steps B - F for all DODAACS in Command.**

VIII. PRINTING CHARTS FROM COMMAND TOTAL FILES

A. Open *COM*TOTL.WQ1. (Command Totals)
Press U for Update Links)

B. Modify Ranges for EUA #13.
(EUA #13 needs human intervention as it is impossible to predict which products will be used in advance. The Total sheets however will show which products were used and need to be plotted. The ranges are already named.) It may also be necessary to modify the scaling values for each chart. The best values can be derived by studying the printed Command Totals. Also estimated values may need to be annotated.

C. Print Base Charts. (EUA #11-#14)

VIII. CREATING DATA FILE FOR COMBINED BASE CHARTS

Due to the fact that Quattro Pro cannot plot more than 6 series of data. It was decided Cricket Graph and MacDraw II (Macintosh graphic programs) would better perform the task of presenting up to 25 bases on one chart. To eliminate possible error in data entry, the data is transferred to the Macintosh rather than re-entered.

IX. CREATING WEAPON TYPE CHARTS

Weapon Type charts are created using chart formats from other charts and changing the data to reflect the bases utilizing the particular weapon.

X. STANDARDIZATION

To more readily understand some of the more complex charts an effort was made to standardize the markers used to indicate individual products.

ANC	Not Used	NAG	D - Empty Box
COK	Not Used	PHO	Not Used
COL	G - Hourglass	PPG	E - X
ELC	H - X in Box	RDF	B - Plus
FOR	Not Used	SHW	A - Filled Square
FSD	C - Asterisk	SOL	Not Used
FSR	F - Filled Triangle	WND	Not Used
HYD	Not Used	WUD	Circle

XI. IDENTIFICATION

Each chart is given a number for identification purposes in the notebooks.

BASE CHARTS

1. Monthly Energy Usage
2. Annual Energy Usage
3. Annual Energy Usage / SQFT
4. Annual Energy Usage / SQFT DDF
5. Product Usage
6. Cost

COMBINED BASES CHART

7. Annual Energy Usage
8. Annual Energy Usage / SQFT
9. Annual Energy Usage / SQFT DDF
10. Cost

COMMAND CHARTS

11. Annual Energy Usage
12. Annual Energy Usage / SQFT
13. Product
14. Cost

WEAPON SYSTEM TYPE OR OTHER

15. Weapon System Type

APPENDIX C

ENERGY/UTILITIES SYSTEMS QUESTIONNAIRES

• MAJCOM Level

• Airbase Level

ENERGY/UTILITIES SYSTEMS QUESTIONNAIRE

(MAJCOM LEVEL)

Date ____________________

1. NAME OF MAJCOM: ____

2. LOCATION OF MAJCOM: ____

3. DCS FOR E&S: ____

4. PRINCIPAL MANAGER OF UTILITY/ENERGY SYSTEMS: __________________

5. MAJCOM MISSIONS:

   Primary: ____

   ____

   Secondary: ____

   ____

   Tertiary: ____

   ____

6. ASSIGNED AIR FORCE SYSTEMS: ___________________________________

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

7. ASSIGNED AIR FORCE BASES:

A listing of the airbases assigned to this command that are recorded in the Defense Energy Information System (DEIS) database is attached. Individual questionnaires for each assigned airbase have also been provided. A review of some of these assigned airbases is planned for the onsite visit. Your efforts to provide some of the information requested in these individual airbase questionnaires will be greatly appreciated.

Number of assigned bases:

Types of assigned bases and number of each type:

____

____

____

____

____

____

Please attach a summary of assigned real estate by class and category code:

Class I - Land

Class II - Improvements

Category 100

Category 200

etc.

8. COMMAND-WIDE UTILITY/ENERGY SYSTEMS:

Electrical Power:

Total number of on-base generating plants: ______________________

Number coal-fired: ______________________

Number oil-fired: ______________________

Number gas-fired: ______________________

Number other-fired: ______________________

Total connected electrical load: ______________________

Total electrical load requiring conditioning: ______________________

Total electrical load requiring UPS: ______________________

Other key information: ______________________

____

____

______________________Continue on separate page as needed)

HVAC Systems (major systems only): ______________________

Heating - number of central steam plants: ______________________

Total central steam plant capacity: ______________________

Cooling - number of central cooling plants: ______________________

Total central cooling plant capacity: ______________________

Air Conditioning - Total capacity: ______________________

Under 10 tons ______________________

Between 10 and 100 tons: ______________________

Over 100 tons: ______________________

Other key information: ______________________

____

____

______________________Continue on separate page as needed)

Water Supply Systems: ____________________

Total number of onbase wells: ____________________

Total number of onbase treatment plants: ____________________

Total on-base production capacity: ____________________

Total purchased from offbase sources previous year: ____________________

Other key information: ____________________

____

____

____

____________________ (Continue on separate page as needed)

Wastewater Systems:

Total number of sewage treatment plants: ____________________

Total quantity processed onbase: ____________________

Total quantity contracted offbase: ____________________

Other key information: ____________________

____

____

____

____________________ (Continue on separate page as needed)

POL:

Total liquid fuel storage capacity: ____________________

Total number of major storage tanks: ____________________

Other key information: ____________________

____

____

____

____________________ (Continue on separate page as needed)

9. DESCRIBE ANY UNUSUAL SYSTEMS BEING USED (Alternative energy, new technology, etc.):

____

____

____

____

(Continue on separate page as needed)

10. TYPES AND QUANTITIES OF ENERGY USED PREVIOUS YEARS:

Energy consumption for each airbase over the past five years has been compiled in the Defense Energy Information System (DEIS) database. These data have recently been extracted and plotted in a variety of charts to provide an understanding and permit an analysis of factors that strongly influence the airbase energy consumption and associated costs. A set of these charts for this MAJCOM has been provided. A review of these charts and discussions of utility/energy trends, which may be revealed by this DEIS data, is planned for the onsite visit.

11. QUANTITIES OF ENERGY USED PREVIOUS YEAR:

Electrical Power: Generated onbase: ______________________

Purchased offbase: ______________________

Natural Gas: ______________________

Propane/Butane/LPG: ______________________

Coal: ______________________

Fuel Oil: ______________________

Onbase Produced Steam: ______________________

Purchased Steam: ______________________

Alternative Energy Systems (onbase):

Solar Thermal: ______________________

Solar Photovoltaic: ______________________

Wind: ______________________

Hydroelectric: ______________________________

Geothermal: ______________________________

Refuse derived fuels: ______________________________

Nuclear: ______________________________

Wood: ______________________________

Automotive Fuels Used for Facility/Utility System Support:

____

Do you keep records of automotive fuels used in support of E&S activities? ______

Diesel fuel consumed previous year: ______________________________

Gasoline consumed previous year: ______________________________

12. APPROVED OR PLANNED UTILITY/ENERGY SYSTEMS PROJECTS:

Retrofit/replacement for regulatory response and/or conservation: ____________

____

____

____

____

____

____

New mission support:

____

____

____

____

____

13. OTHER ENERGY INFORMATION SYSTEM REPORTS:

Are there any other utility/energy reports or data files that precede or augment the DEIS system? Can copies be provided?

____

____

14. PROJECTED ASSIGNMENT OF AIR FORCE SYSTEMS:

Are you aware of any projected future assignment of new or different Air Force systems or increases in numbers of currently assigned systems on your airbases?

Please describe: ____

____

____

____

Will these require any changes or increases in energy/utility system to provide adequate support?

Please describe: ____

____

____

____

15. AIRBASE ENERGY/UTILITY PROBLEM AREAS:

Describe any airbase energy/utility problem areas that you are aware of: ____________

____

____

____

____

____

____

Can any of these problem areas be solved with commercially available (off-the-shelf) equipment?

____

____

____

____

____

____

Are there any energy/utility systems or components that could be made more efficient or more cost effective?

Please describe: ____

____

____

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____

____

16. PROJECTED ENERGY/UTILITY INCREASES:

What levels of energy/ utility increases are you expecting and planning for over the next 5, 10, and 30 years, and what will be the causes for these increases?

____

____

____

____

____

____

____

____

____

(Continue on separate page as needed)

17. OFF-BASE ENERGY/UTILITY SUPPLIERS:

Is there a high degree of confidence in the ability of your offbase suppliers to meet your future energy/utility requirements over the next 30 years? If not, have plans for alternative supplies or different approaches for meeting energy/utility requirements been formulated?

Please describe: ______________________________

(Continue on separate page as needed)

18. DO YOU HAVE ANY RECOMMENDATIONS FOR ENERGY/UTILITY SYSTEM R&D THAT WOULD BENEFIT THE AIR FORCE NOW OR AT VARIOUS TIMES OVER THE NEXT 30 YEARS?

Please describe: ______________________________

(Continue on separate page as needed)

ENERGY/UTILITIES SYSTEMS QUESTIONNAIRE

(AIRBASE LEVEL)

Date ____________________

1. NAME OF AIRBASE: ____

2. LOCATION OF AIRBASE: ____

   ____

3. MAJOR COMMAND: ____

4. WING/BASE COMMANDER: ____

5. BASE CIVIL ENGINEER: ____

6. PRINCIPAL UTILITY/ENERGY SYSTEMS MANAGER: _______________________

7. AIRBASE MISSIONS:

   Primary: ____

   ____

   Secondary: ____

   ____

   Tertiary: ____

   ____

8. ASSIGNED AIR FORCE UNITS AND SYSTEMS (MAJOR UTILITY/ENERGY USERS):

   ____

   ____

   ____

   ____

   ____

   ____

   ____

9. SIZE OF AIRBASE:

Area (acres): ______________________________

Total number of buildings/facilities: ______________________________

Total floor area of buildings/facilities: ______________________________

Number of people occupied bldgs: ______________________________

Total floor area of people occupied buildings/facilities: ______________________________

Identify and describe special high energy consumption buildings/facilities:

____

____

____

____

10. DESCRIPTION OF UTILITY SYSTEMS (Attach drawings/documentation as appropriate):

Electrical Power:

Total number of onbase generating plants: ______________________________

Types of fuel used: ______________________________

Total connected electrical load: ______________________________

Quantity generated onbase: ______________________________

Quantity purchased from offbase: ______________________________

Connected load requiring conditioning: ______________________________

Connected electrical load requiring UPS: ______________________________

Electrical power system description: ______________________________

____

____

____

____

____

____

____

(Continue on separate page as needed)

HVAC Systems:

Heating - number of central steam plants: ____________________

Total central steam plant capacity: ____________________

Cooling - number of central cooling plants: ____________________

Total central cooling plant capacity: ____________________

Air Conditioning - Total capacity: ____________________

Under 25 tons: ____________________

Between 25 and 100 tons: ____________________

Over 100 tons: ____________________

Types/amounts of refrigerants used (R-11,R-12,etc.)

____

____

HVAC System Description: ____________________

____

____

____

____

____

(Continue on separate page as needed)

Water Supply:

Number of onbase wells: ____________________

Quantity produced onbase: ____________________

Quantity purchased from other sources: ____________________

Water Supply System Description: ____________________

____

____

____

____

(Continue on separate page as needed)

Wastewater:

Number of onbase processing plants: ____________________

Total quantity processed annually: ____________________

Quantity processed onbase ____________________

Quantity processed offbase ____________________

Wastewater system description: ____________________

____

____

____

____

(Continue on separate page as needed)

POL:

Total liquid fuel storage capacity: ____________________

Total number of major storage tanks: ____________________

POL System Description: ____________________

____

____

____

____

____

(Continue on separate page as needed)

11. TYPES AND QUANTITIES OF ENERGY USED IN PREVIOUS YEARS:

Energy consumption for this airbase over the past five years has been compiled in the Defense Energy Information System (DEIS) database. These data have recently been extracted and plotted in a variety of charts to provide an understanding and permit an analysis of factors that strongly influence the airbase energy consumption and associated costs. A set of these charts has been provided. A review of the charts and discussions of utility/energy trends, which may be revealed by these DEIS data, is planned for the onsite visit.

Electrical power: Generated onbase: ______________________

Purchased offbase: ______________________

Natural Gas: ______________________

Propane/Butane/LPG: ______________________

Coal: ______________________

Fuel Oil: ______________________

Onbase Produced Steam: ______________________

Purchased Steam: ______________________

Alternative Energy Systems (onbase):

Solar Thermal: ______________________

Solar Photovoltaic: ______________________

Wind: ______________________

Hydroelectric: ______________________

Geothermal: ______________________

Refuse derived fuels: ______________________

Nuclear: ______________________

Wood: ______________________

Automotive Fuels Used for Facility/Utility System Support (Include fixed and mobile emergency generators):

Diesel fuel: ______________________

Motor vehicle gasoline: ______________________

12. ENERGY INFORMATION SYSTEM REPORTS:

Are there any other utility/energy reports or data files that precede or augment the DEIS system? Can copies be provided?

____

____

13. APPROVED OR PLANNED CHANGES OR ADDITIONS TO UTILITY/ENERGY SYSTEMS:

(Continue on separate page as needed)

14. UTILITY/ENERGY DIRECT TIES TO AIR FORCE SYSTEMS:

Describe any direct ties or requirements between airbase utility/energy systems and assigned Air Force systems over and above normal airbase operational activities:

(Continue on separate page as needed)

15. UTILITY/ENERGY SYSTEM MONITORING AND BILLING:

Is the utility/energy consumption for each building/facility monitored separately? ______

If not,describe the metering/monitoring system that is used: ____________________

How are the individual operating units and/or tenant units on the base billed for utility/energy costs?

16. PROJECTED ASSIGNMENT OF AIR FORCE SYSTEMS:

Are you aware of any projected future assignment of new or different Air Force systems or increases in numbers of currently assigned systems on your airbase? Please describe:

Will these require any changes or increases in energy/utility system to provide adequate support?

Please describe: ____________________

17. AIRBASE ENERGY/UTILITY PROBLEM AREAS:

Describe any airbase energy/utility problem areas that you are aware of:

Can any of these problem area be solved with commercially available (off-the-shelf) equipment?

Are there any energy/utility systems or components that could be made more efficient or more cost effective?

Please describe:

18. PROJECTED ENERGY/UTILITY INCREASES:

What levels of energy/utility increases are you expecting and planning for over the next 5, 10, and 30 years, and what will be the causes for these increases?

____
____
____
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____
____

(Continue on separate page as needed)

19. OFFBASE ENERGY/UTILITY SUPPLIERS:

Who are your offbase energy/utility suppliers?

____
____
____

Is there a high degree of confidence in their ability to meet your future energy/utility requirements over the next 30 years? If not, have plans for alternative supplies or different approaches for meeting energy/utility requirements been formulated?

Please describe: ____
____
____
____
____
____
____
____
____
____

(Continue on separate page as needed)

20. DO YOU HAVE ANY RECOMMENDATIONS FOR ENERGY/UTILITY SYSTEM R&D THAT WOULD BENEFIT THE AIR FORCE NOW OR AT VARIOUS TIMES IN THE FUTURE?

Please describe: ____

(Continue on separate page as needed)

(The reverse of this page is blank.)

APPENDIX D

OPERATING COGENERATION PLANTS

• UNM Cogeneration Plant

DRAFT

COGENERATION SYSTEMS
AT THE
UNIVERSITY OF NEW MEXICO

by

La ıce Schuster
C G. Leigh
Jo Schrader

February 1991

EXECUTIVE SUMMARY

The University of New Mexico (UNM) chilled water distribution system has been severely strained for several years. Until 1989 no additional cooling capacity had been added to the system since 1979. This prevented UNM from providing reliable service to many critical areas on campus, e.g., the Computer and Information Resources and Technology (CIRT) facility. To assure a high degree of reliability, CIRT requires continuous power and cooling to computer equipment. The traditional solution would have been to provide high-quality power through an uninterruptible power supply (UPS) backed up by a diesel emergency generator, for the campus distribution system, at a cost of $1.25 million. An alternative solution was devised to provide chilled water and power to both CIRT and the campus.

The UNM Physical Plant, Energy Conservation Office, determined that installing a natural gas-fired combustion turbine/generator with a waste heat boiler in a structure located near the UNM parking structure and CIRT would be a far better alternative. The generator produces approximately 2500 kW, and the hot turbine exhaust gas produces steam in a waste heat boiler. The steam is used by either an absorption chiller to provide chilled water to the campus or is injected directly into the campus steam lines. The system will pay for itself with reduced utility costs.

The generator and chiller are large enough to meet 100 percent of the electrical and cooling requirements of CIRT. Excess power is redistributed on the campus grid. In the event of a power failure, the plant acts as an emergency generator, providing power and cooling to CIRT as long as natural gas is available.

An economic analysis, indicated that the proposed turbine-generator set would save UNM approximately $48,333 per month or $580,000 in the first year, compared to present costs. Installation first cost was $3.2 million. Ten-year financing yielded positive cash flow immediately and had a net present value of $1.1 million. The financial aspects are detailed in this paper.

SECTION 1
INTRODUCTION

For the past five years, UNM has suffered from lack of reliable chilled water flow to all portions of the campus. As buildings have been added to the campus chilled water distribution system, the problem has worsened. Until 1989 no additional chilled water production capacity had been added to the system since 1979. There has also been a critical need for backup electrical and cooling energy for the Computer and Information Resources and Technology (CIRT) facility to assure the high reliability requirements they have set for operations. Unfortunately, neither UNM's utility plants nor the Public Service Company of NM (PNM) could provide power, and thermal energy with the reliability needed by CIRT since the building is located at the remote end of the chilled water distribution system.

Normally, a diesel emergency generator and local chilled water generator would be used for this purpose, but an alternative solved both problems and also reduced the University's utility costs at the same time. The alternative consists of a natural gas-fired turbine/generator and waste heat boiler, coupled to an electric generator and chilled water generator. The gas turbine drives a generator sized to meet the needs of CIRT and the Cogeneration Plant itself. The remaining 1.5 MW of power are available for redistribution throughout the UNM campus. The hot turbine exhaust gases are routed to a waste heat boiler that produces steam at 40 lb/in.^{2}g. The steam is used in the chilled water generator (chiller), and any excess is injected into the campus steam distribution lines.

The generator acts as the primary source of power for CIRT and the Cogeneration Plant, supplying electrical and thermal energy continuously and exporting the balance to the UNM electrical and chilled water distribution systems. Other UNM utility plants and PNM act as backup in case of a failure. This paper describes the design concept for the system and analyzes the financing arrangement.

The Cogeneration Plant is constructed near the main entrance to the Parking Structure west of CIRT. The plant houses all required electrical and mechanical equipment and switchgear.

A. DESIGN CONCEPT

1. Power Generation

The cogeneration system is composed of a natural-gas fired combustion turbine/generator and waste heat boiler. The turbine is similar to a jet engine that is fired with natural gas rather than jet fuel. The turbine produces shaft power that drives a synchronous electrical generator. The generator voltage is 486-volt, three-phase power, which is stepped up to 4160-volt, three-phase power and distributed on the primary side of the CIRT main transformer with a separate export feeder run directly to the UNM electrical substation. Relay protection was required on the feeders, however, to ensure they are never energized when work is being performed at the main substation. Because the output of the generator is such a small percentage of the total campus electrical demand (2.5 vs. 16 MW), no power is sold to PNM.

Normally the generator runs continuously at its rate output of 2500 kW, exporting excess power not required by CIRT and the Cogeneration Plant to the campus grid. Whenever utility power is lost, the system automatically switches into an isolated condition and supplies power to CIRT on an emergency and uninterruptible basis. Power is available as long as natural gas is available. The only time the CIRT is without power is when a simultaneous interruption in both utility gas and electricity occurs. Since this is an unmanned plant, automatic synchronization with restoration of utility power is provided. Remote indications are provided to the Central Campus Computer System to alert operations personnel to operations and maintenance status and alarms.

2. Chilled Water Production

The gas turbine produces hot exhaust gas as a byproduct of the combustion process. The hot gases are directed to a waste heat boiler that produces steam at 40 lb/in.^{2}. The steam is either injected into the campus steam lines or is used to produce chilled water in an absorption chiller. The absorption chiller uses a chemical process to allow the steam to be used directly in the production of chilled water. The plant chilled water piping is connected directly to the existing campus chilled water distribution piping.

The waste heat boiler produces enough steam to run a 1000-ton absorption chiller, which is sufficient for CIRT and most of the needs of the main campus.

B. ECONOMIC ANALYSIS

The project was analyzed by determining the effect the Cogeneration Plant would have had on the University utility budget had it been operating during the previous 12 months. Actual electrical and gas charges were broken into their component parts, and the effect of the generator was determined on each component of the utility bill. For example, the effect of the generator on the electrical bill is two-fold: it reduces both the energy usage component of the bill and the demand component. Both effects were determined individually.

The analysis indicated that the unit would produce approximately 21 million kWh electricity, 2.7 million ton-hours of refrigeration, and 50 million pounds of steam annually. The revenue generated by the sale of these utilities to other University elements is estimated to be $1,943,500 per annum. The operations and maintenance expenses of the Cogeneration Plant are estimated to be $1,363,500 per annum leaving a base net income of $580,000 per year. Actual performance for FY 1990 provided 14 million kWh of electricity, 3.2 million ton-hours of refrigeration equivalent (chilled water), and 43 million pounds of steam. Projections of the base income were extended for 10 years based on escalation rates for gas and electric energy compiled by the Public Service Company of New Mexico, the National Bureau of Standards, the American Gas Association, and UNM historical cost.

The plant was financed at 6 percent as part of a UNM revenue bond issue. The $417,000 annual payments on the bonds are made semiannually leaving a positive net cash flow of $163,000 for contingencies. Based on the projections, this cash flow will rise to $408,500 in the tenth year.

Because UNM is being allowed to retain the economic benefits of the plant by billing energy produced by the plant as if it were purchased from outside utilities, UNM did not have to request capital funding from the State of New Mexico. This freed scarce funds for other purposes and allowed UNM to see real economic benefits. After the bonds are retired, the entire energy cost savings of $580,000 per year will be realized.

C. CONCLUSIONS

Cogeneration is all its different forms should be viewed as one more alternative to conventional systems. When compared against conventional systems, cogeneration systems hold forth the probability of providing the same service and function with the possibility of paying for and operating the system with the revenues produced. Even if the system cannot achieve a payback or a positive cash flow, it may still be a lower life-cycle cost alternative than any of the conventional alternatives. When faced with new installations or replacement of boilers, chillers, compressors, or other machinery, cogeneration may yield the best solution. By combining the requirements of several different facilities or projects, a single cogeneration plant may provide all the answers.

SECTION II
SYSTEM DESCRIPTION

A. GENERAL DESCRIPTION

The UNM Cogeneration Plant is balanced steam, chilled water, and electrical power generation facility constructed in 1989 to meet an increased on-campus need for various energy products (Figure D-l). The heart of the system is a combustion gas turbine fueled with natural gas. The gas turbine power shaft is connected through a gearbox to a 3000 kW synchronous electric generator. The hot exhaust gases from the turbine are routed through a water pipe-type steam boiler to produce steam, and then are vented to the atmosphere through a heat recovery "economizer" heat exchanger. The recovered heat from the economizer is used to preheat the boiler feed water. All of the above equipment is mounted (packaged) on a steel skid base.

The steam from the boiler is fed into a lithium bromide/water absorption chiller to produce chilled water (42 °F). The chilled water can be circulated directly for cooling CIRT or fed into the campus cooling system for other buildings. Similarly, the steam from the boiler can also be used for heating CIRT during the winter or introduced into the campus steam heating system.

The entire UNM Cogeneration Plant is housed in a 4200-ft^2 facility located near CIRT and is a short distance from the campus power grid station.

B. SYSTEM COMPONENTS

1. Gas Turbine

Supplier: Solar (Subsidiary of Caterpillar)
Model: Center TK 4500
Size: 3000 kW (at sea level, 2500 kW at 5400-foot elevation of Albuquerque)

This is a standard gas con . ustion turbine similar to an early model jet aircraft engine. A newer model gas turbine with the same physical size is now available from solar and will produce 4000 kW at sea level.

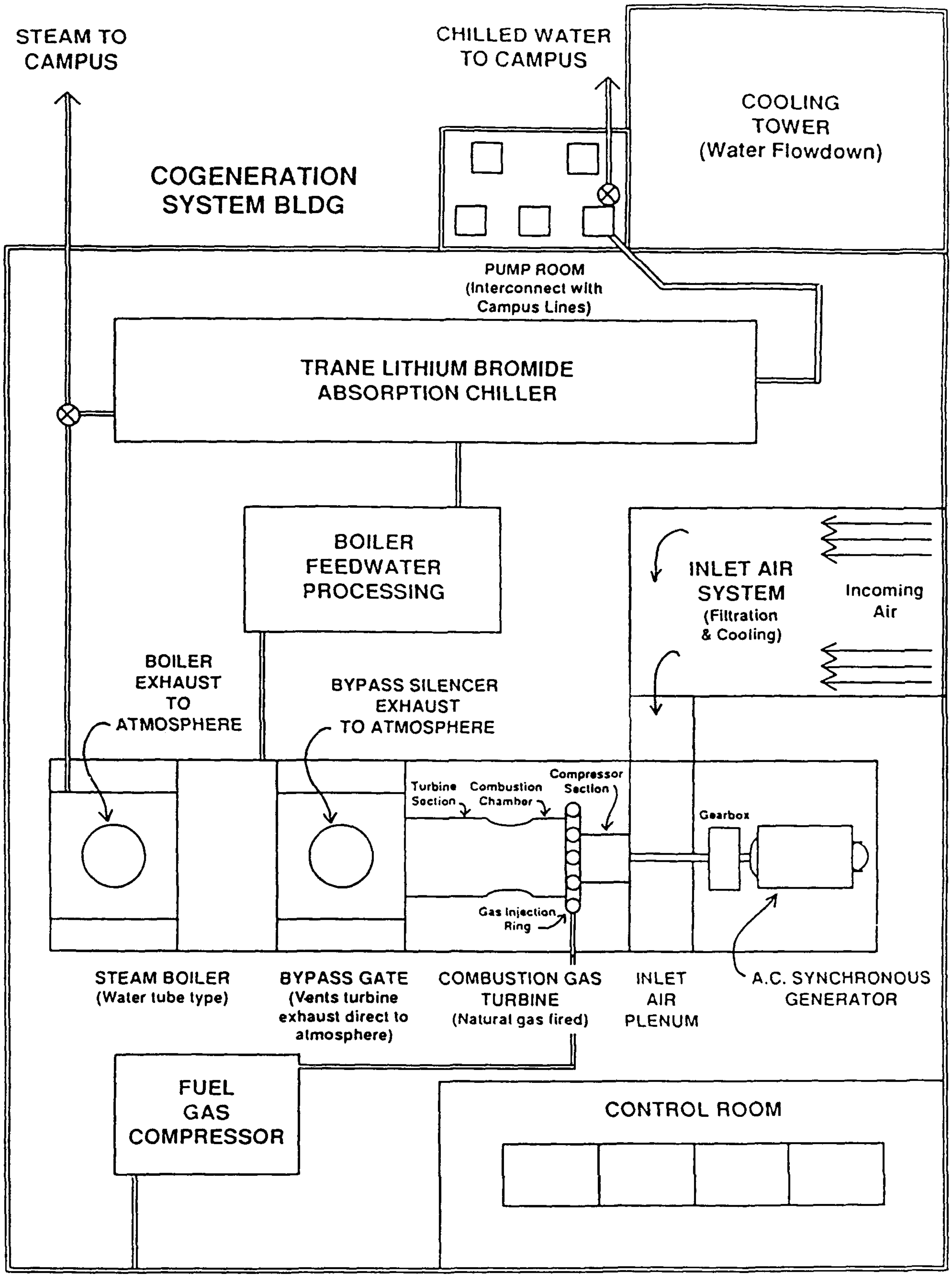

Figure D-1. A Schematic of the UNM Cogeneration Plant.

2. Boiler

Supplier: Energy Recovery, Inc. (purchased from Nebraska Boiler Company)

Model: S2-1616 (with economizer)

Size: 17,000 lbs/hr at 50 $lb/in.^2$

This standard water tube boiler uses a waste heat recovery economizer to preheat boiler feed water to 50 °F. Exhaust gases enter the boiler at about 1000 °F pass through to the economizer at about 500 °F and exit at about 250 °F. The boiler is set to produce steam at 60 $lb/in.^2$ to feed into the campus steam lines. The steam pressure is reduced to 15 $lb/in.^2$ for input to the absorption chiller.

3. Absorption Chiller

Supplier: Trane

Model: ABSC

Size: 1000 Tons

This lithium bromide/water absorption chiller uses 5 $lb/in.^2$ steam heat to vaporize and separate water from a Li Br/water mixture. The separated water vapor is cooled and condensed to liquid water, which is then spray-mixed with the concentrated LiBr. The absorption of the water into the Li Br greatly reduces the temperature of the mixture, which is then cascaded down over pipes through which the water to be chilled is circulated. The temperature of this refrigerant water is reduced from 58 °F to 42 °F. The Li Br/water mixture settles in the bottom of the vacuum tank where it is pumped back to the top to repeat the process. When in full operation, all of the steam from th· Cogeneration Plant is fully utilized to operate the chiller. For future expansion, the existing single-stage Trane unit can be replaced with a two-stage Hitachi or Sanyo unit and supplied with 125 $lb/in.^2$ steam to double the cooling capacity.

4. Generator

Supplier: KATD

Model:

Size: 3000 kW

This is a standard synchronous electrical generator, which is connected to the turbine output shaft through a speed reducing gearbox. Generator speed is 3600 rpm.

5. Cooling Tower

Heat from the chiller is removed with water which is then passed through a standard, trickledown, ceramic cooling tower. Water enters the cooling tower at 90 °F and returns to the chiller at 80 °F. If a domestic hot water or hot water space-heating loop were available, much of this wasted heat could be utilized.

6. Fuel System

Natural gas received from local pipelines at 50 $lb/in.^2$ is compressed to 160 $lb/in.^2$ (and cooled). It is passed through a dual filter system and injected into the gas turbine via the fuel ring. (Note: Multiple fuel turbines can be specified that will permit use of liquid fuels [diesel, JP-8] for backup. The UNM Cogeneration Plant does not require a backup fuel system because backup power can be supplied by the power grid or the campus heating plant.)

7. Turbine Air Intake

Combustion air (30,000 cf/m) is brought into the turbine through a filter and bag room. Several stacks of filters and two bag filters are used to ensure absolute cleanliness of the air entering the compressor section of the turbine. In addition, during summer months, the inlet air is passed through an evaporative cooler to increase its density. This step provides about a $60,000 per year increase in electrical power production.

8. Control Systems

Several control panels are used to operate the entire Cogeneration Plant. An Allen Bradley control panel, supplied by Solar with the turbine, controls the operation of all of the electrical and mechanical systems of the cogeneration package on the skid base (turbine, boiler, bypass gate, etc.). A Baylor electrical power control panel regulates all of the electrical power output and interconnection with the power grid and campus substation. A key feature of this system is the ability to switch from cogenerated electrical power and grid supplied power in less than one cycle. All of these control panels are enclosed in a separate control room inside the plant building.

9. Post-Turbine Fuel Injection

The exhaust gases exiting from the turbine contain an excess of oxygen, a phenomenon which provides an opportunity for the highly efficient combustion of additional fuel injected just upstream of the boiler. This turbine exhaust combustion of this fuel can increase both the production of thermal energy (steam) and the overall system conversion efficiency by as much as 5 percent.

A second application of post-turbine fuel injection is the production of higher pressure/temperature steam, which can then be used to drive a small steam turbine to produce more electrical power. Although highly efficient in terms of energy conversion, such combined cycle systems can be capital-intensive for acquisition. The UNM Cogeneration Plant does not include any of these additional features.

10. Exhaust Vented to Atmosphere

The final turbine exhaust is vented directly to atmosphere, either after passing through the boiler and economizer or after bypassing the boiler. The emissions from this small turbine do not need further processing to meet air quality requirements for Albuquerque, a benefit not necessarily accruing to large or multiple turbines.

11. Component Enclosures

Since all of the UNM Cogeneration Plant is enclosed inside of a building, all system components where a fuel leak could reasonably occur or where a fire could ignite are enclosed in cabinets with filtered forced air ventilation and built-in fire detection sensors linked to a fire alarm system in the control room. In addition, filtered cooling air is supplied to the generator enclosure cabinet.

12. Feed Water Conditioning

A feed water conditioning system is used for filtering, deairation (removal of oxygen), and demineralization of feed water prior to entering the boiler.

C. SYSTEM EFFICIENCY/COST

The system was designed to achieve approximately 80 percent overall conversion of fuel energy into useful energy products (electricity and steam) and to produce 2.5 MW of power. The performance measured over the first 18 months of operation was 2.1 MW of power and 79.6 percent conversion of energy. Additional fine tuning may yet improve this performance.

The total installed cost for the complete cogeneration and chiller plant and building was \$3.2 million in 1989. Approximately \$1 million of this cost was for the absorption chiller part of the plant. The costs of the remaining \$2.2 million associated with the cogeneration energy conversion and the enclosing building are as follows:

$$\frac{\$2,200,000}{2100} = \$1048 \, / \, \text{installed kW}$$

These figures are very near those of new commercial power plants that produce only electricity. The UNM Cogeneration Plant now carries about 15 percent of the average campus electrical load.

SECTION III
PRELIMINARY ANALYSIS OF SYSTEM PERFORMANCE

Data from the first 18 months of operation of the UNM Cogeneration Plant have been recorded and a preliminary analysis accomplished. The measured data have been converted to common units (MBtus) in Table D-1 and tabulated in pertinent categories (Table D-2). These data have then been plotted as a function of time in Figures D-2 through D-7.

Figure D-2 shows the amount of fuel gas consumed and the steam and electric power produced over this period. Figure D-3 shows the steam and electricity produced and also the overall efficiency of the Cogeneration Plant during these first 18 months of operation. Figure D-4 shows the total electricity produced and where it was used. Figure D-5 shows the production and use of steam, while Figure D-6 shows the percent of steam used to make chilled water. Figure D-7 shows the amount of electrical power used by the Cogeneration Plant as parasitic power.

TABLE D-1. ENERGY DATA FROM UNM COGENERATION PLANT CONVERTED TO MBTUS.

Month	Generator Production (MBtu)	Plant Use (MBtu)	Computer Center (MBtu)	Exported (MBtu)	Steam Produced (MBtu)	Steam to Heat (MBtu)	Steam to CHW (MBtu)	Chill Water (MBtu)	Gas Used Gulf Reading (MBtu)	Gas Used UNM (MBtu)
Jul 89	778.2	598.0	0.0	180.2	1,906.8	0.0	5,764.7	8,895.7	2,874.9	3,694.7
Aug 89	3,781.6	726.3	0.0	3,055.3	10,386.3	0.0	10,386.3	7,874.1	16,464.0	17,208.5
Sep 89	4,300.4	720.0	0.0	3,580.4	11,954.1	0.0	11,954.1	7,812.1	17,770.1	20,279.4
Oct 89	2,113.3	384.7	0.0	1,728.3	7,110.0	0.0	7,110.0	3,788.8	16,495.0	17,872.9
Nov 89	4,662.2	678.2	0.0	3,981.7	12,525.0	4,046.8	8,478.2	4,218.0	14,538.9	21,765.9
Dec 89	3,220.5	484.6	0.0	2,735.9	8,913.7	1,373.8	7,539.9	3,751.2	20,823.2	15,153.2
Jan 90	2,192.5	388.8	0.0	1,803.7	6,413.2	0.0	6,584.8	2,791.6	3,149.9	10,096.5
Feb 90	3,593.2	614.4	0.0	2,984.9	10,182.7	126.0	10,056.7	6,003.2	19,118.2	17,389.9
Mar 90	4,968.0	331.4	0.0	4,632.9	12,612.1	9,029.5	3,582.6	2,090.0	18,176.1	19,927.7
Apr 90	1,778.9	244.9	0.0	1,537.5	5,060.6	2,151.0	2,909.7	1,447.6	13,898.1	7,374.7
May 90	3,914.0	589.2	0.0	3,324.8	9,839.8	833.6	9,006.1	5,376.8	10,568.8	17,354.7
Jun 90	3,660.1	621.2	0.0	3,038.9	9,538.0	0.0	9,538.0	5,389.5	14,650.0	16,338.4
Jul 90	5,140.0	768.4	0.0	4,361.0	13,871.0	4,203.8	9,667.2	4,328.6	21,871.0	23,347.9
Aug 90	5,226.0	772.4	0.0	4,453.6	14,167.6	4,079.2	10,088.3	4,517.2	23,293.9	23,705.0
Sep 90	4,693.6	709.4	0.0	3,984.2	13,072.2	6,388.7	6,683.5	3,520.8	22,057.7	21,355.0
Oct 90	5,131.8	779.8	0.0	4,352.0	13,546.2	8,617.1	4,929.1	2,452.3	23,225.3	23,423.4
Nov 90	5,040.3	413.5	0.0	4,628.8	12,663.0	11,112.9	1,550.1	771.2	21,961.8	22,391.9
Dec 90	4,604.8	197.9	56.7	4,353.6	10,934.1	10,934.1	0.0	0.0	0.0	19,662.0

TABLE D-2. ENERGY CONVERSION EFFICIENCY.

Month	Gas Consumed (MBtu)	Electricity Produced (MBtu)	Electric Efficiency (%)	Steam Produced (MBtu)	Steam Efficiency (%)	Overall Efficiency (%)	Plant Usage (MBtu)	Percentage of Consumption
Jul 89	3,694.7	778.2	21.1	1,906.8	51.6	72.7	598.0	16.2
Aug 89	17,208.5	3,781.6	22.0	10,386.3	60.4	82.3	726.3	4.2
Sep 89	20,279.4	4,300.4	21.2	11,954.1	58.9	80.2	720.0	3.6
Oct 89	17,872.9	2,113.3	11.8	7,110.0	39.8	51.6	384.7	2.2
Nov 89	21,765.9	4,662.2	21.4	12,525.0	57.5	79.0	678.2	3.1
Dec 89	15,153.2	3,220.5	21.3	8,913.7	58.8	80.1	484.6	3.2
Jan 90	10,096.5	2,192.5	21.7	6,413.2	63.5	85.2	388.8	3.9
Feb 90	17,389.9	3,593.2	20.7	10,182.7	58.6	79.2	614.4	3.5
Mar 90	19,927.7	4,968.0	24.9	12,612.1	63.3	88.2	331.4	1.7
Apr 90	7,374.7	1,778.9	24.1	5,060.6	68.6	92.7	244.9	3.3
May 90	17,354.7	3,914.0	22.6	9,839.8	56.7	79.3	589.2	3.4
Jun 90	16,338.4	3,660.1	22.4	9,538.0	58.4	80.8	621.2	3.8
Jul 90	23,347.9	5,140.0	22.0	13,871.0	59.4	81.4	768.4	3.3
Aug 90	23,705.0	5,226.0	22.0	14,167.6	59.8	81.8	772.4	3.3
Sep 90	21,355.0	4,693.6	22.0	13,072.2	61.2	83.2	709.4	3.3
Oct 90	23,423.4	5,131.8	21.9	13,546.2	57.8	79.7	779.8	3.3
Nov 90	22,391.9	5,040.3	22.5	12,663.0	56.6	79.1	413.5	1.8
Dec 90	19,662.0	4,604.8	23.4	10,934.1	55.6	79.0	197.9	1.0

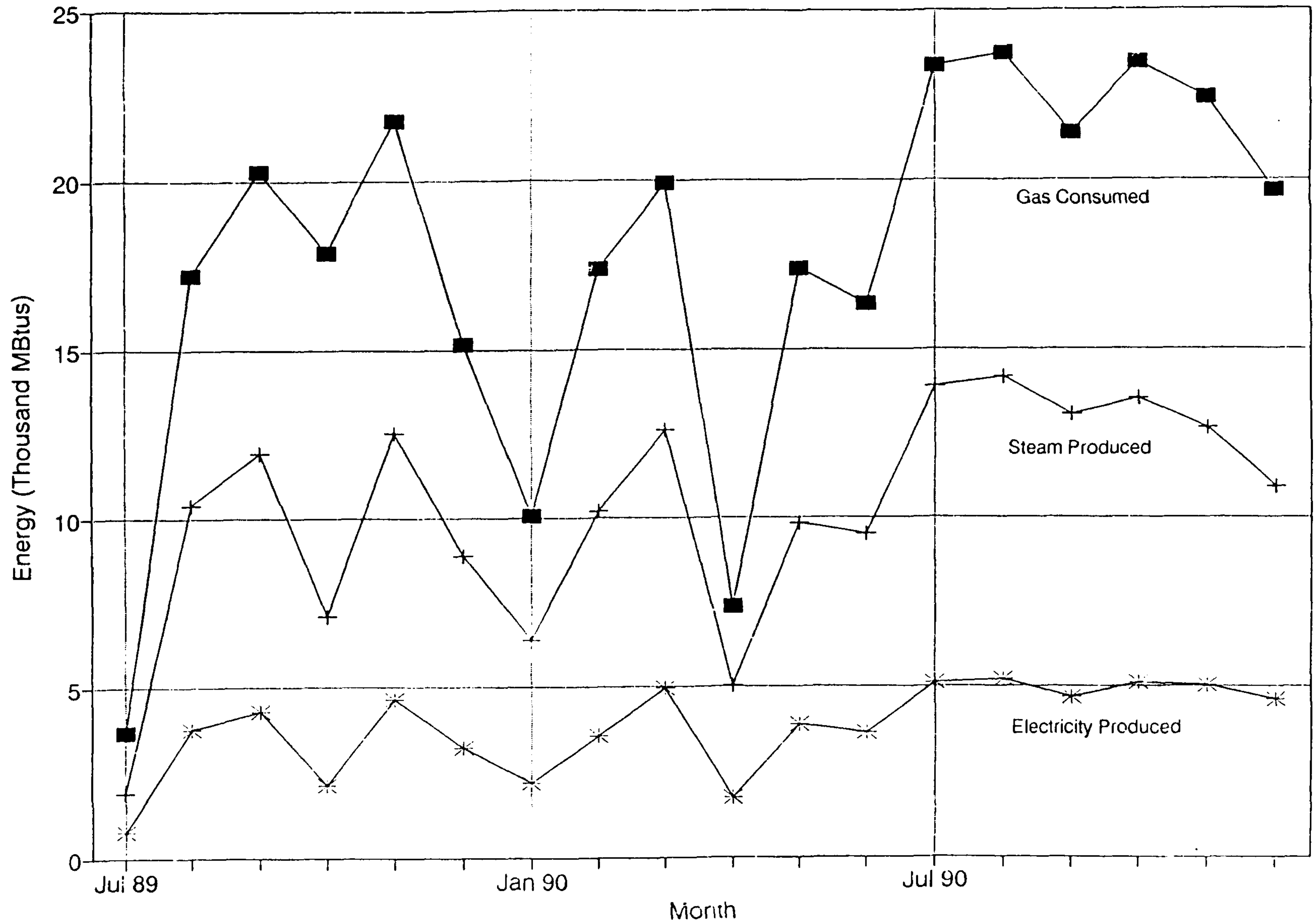

Figure D-2. Cogeneration Energy Consumption and Production.

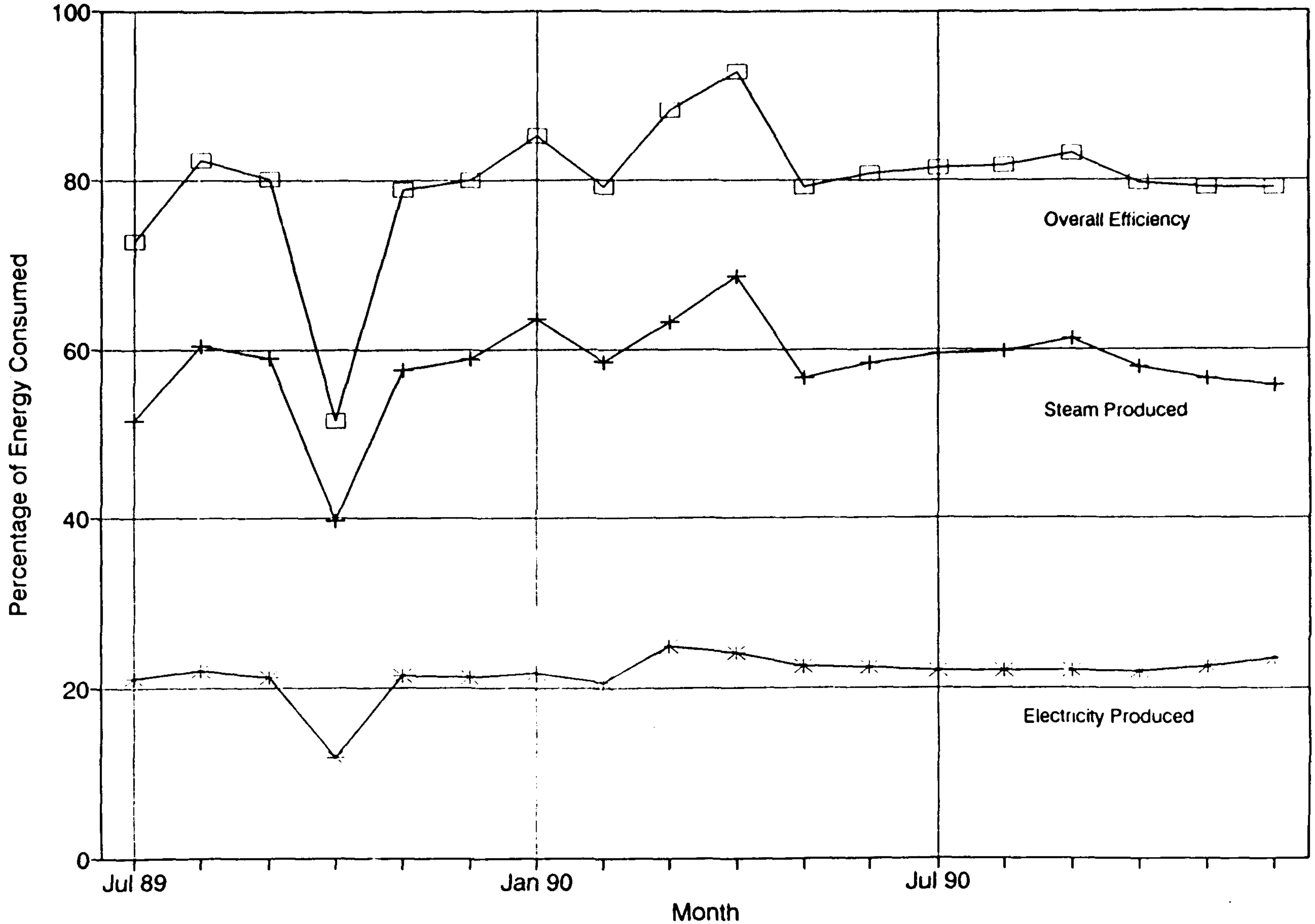

Figure D-3. Cogeneration Plant Energy Conversion Efficiency.

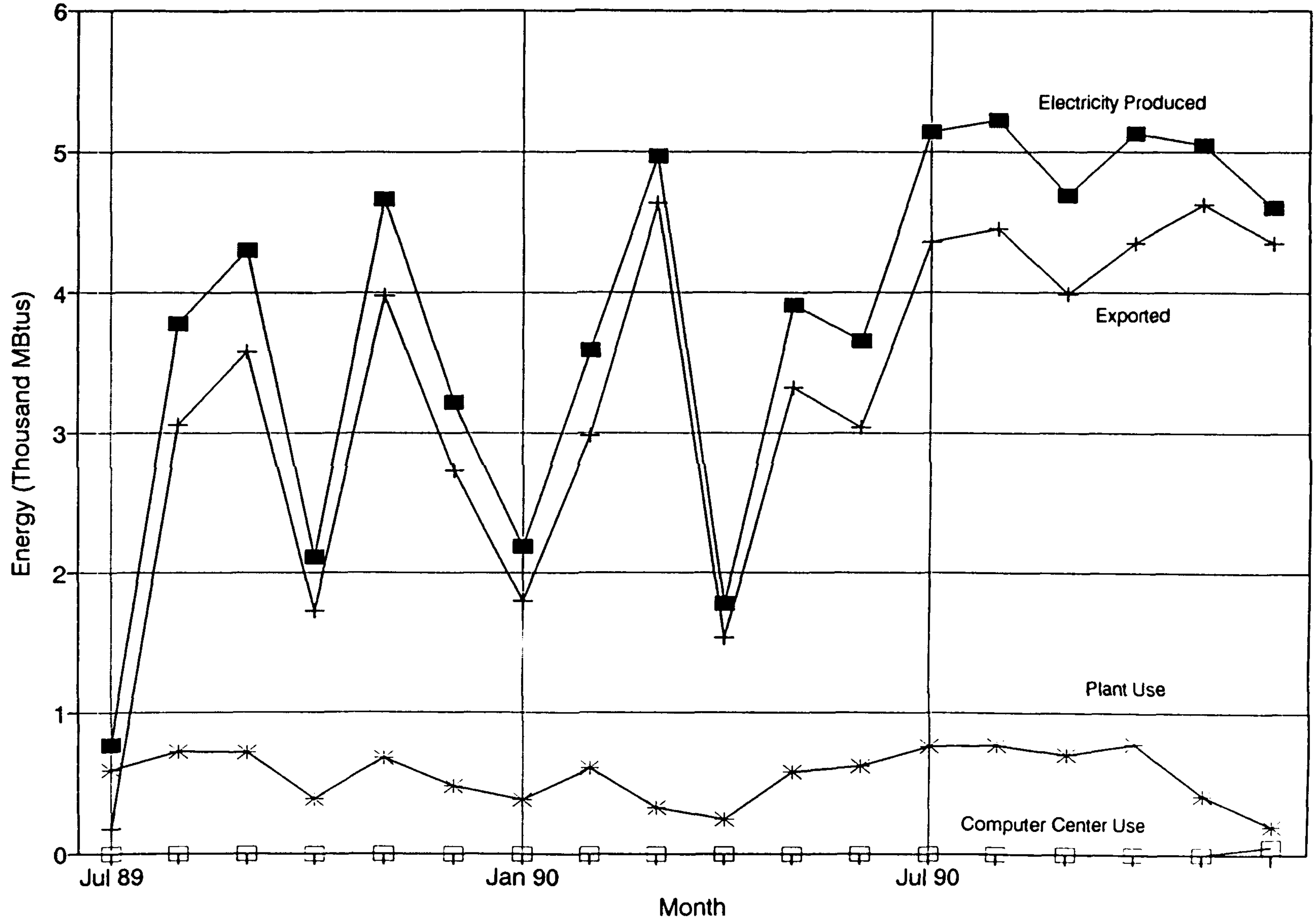

Figure D-4. Generator Electricity Production and Use.

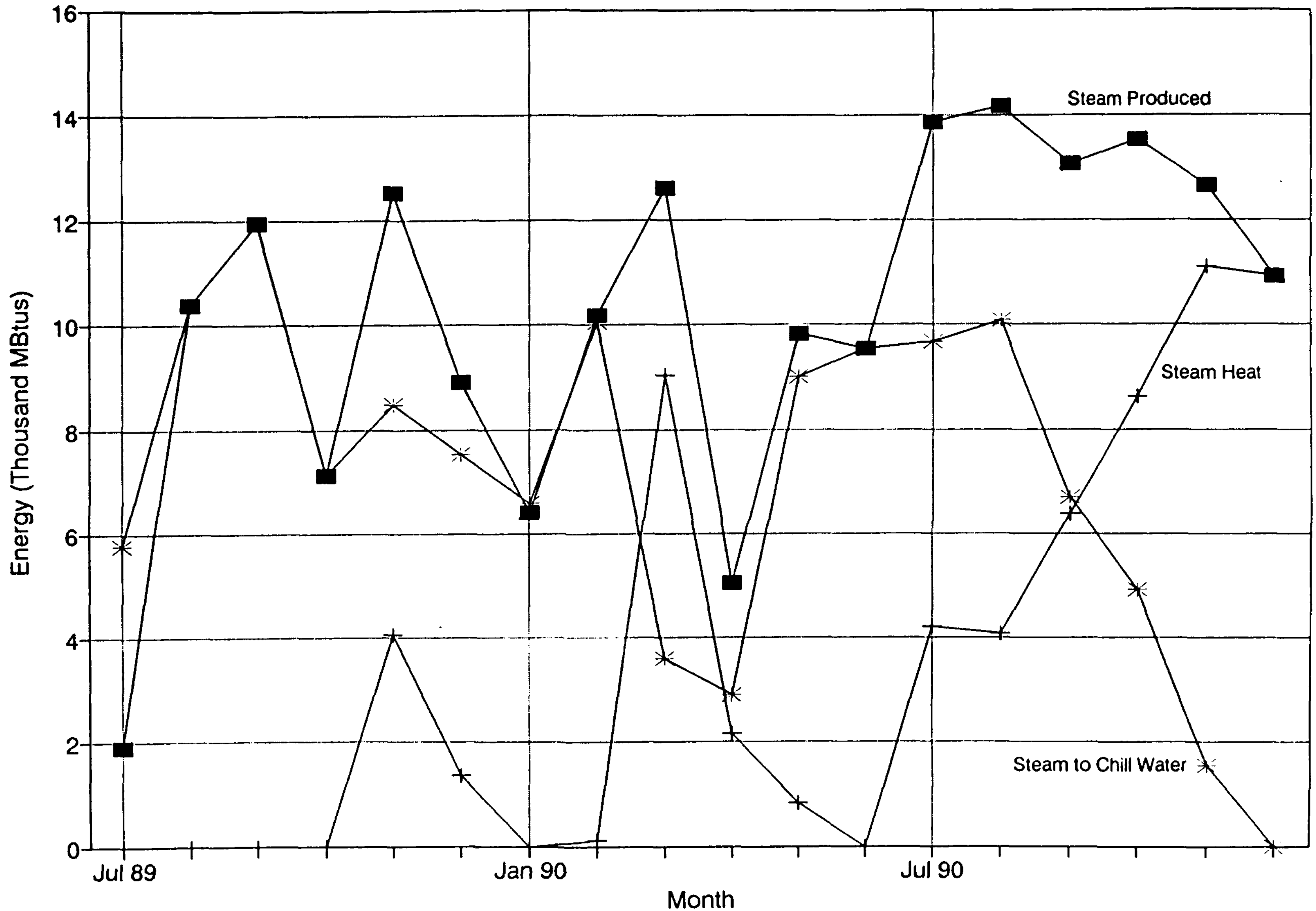

Figure D-5. Steam Production and Use.

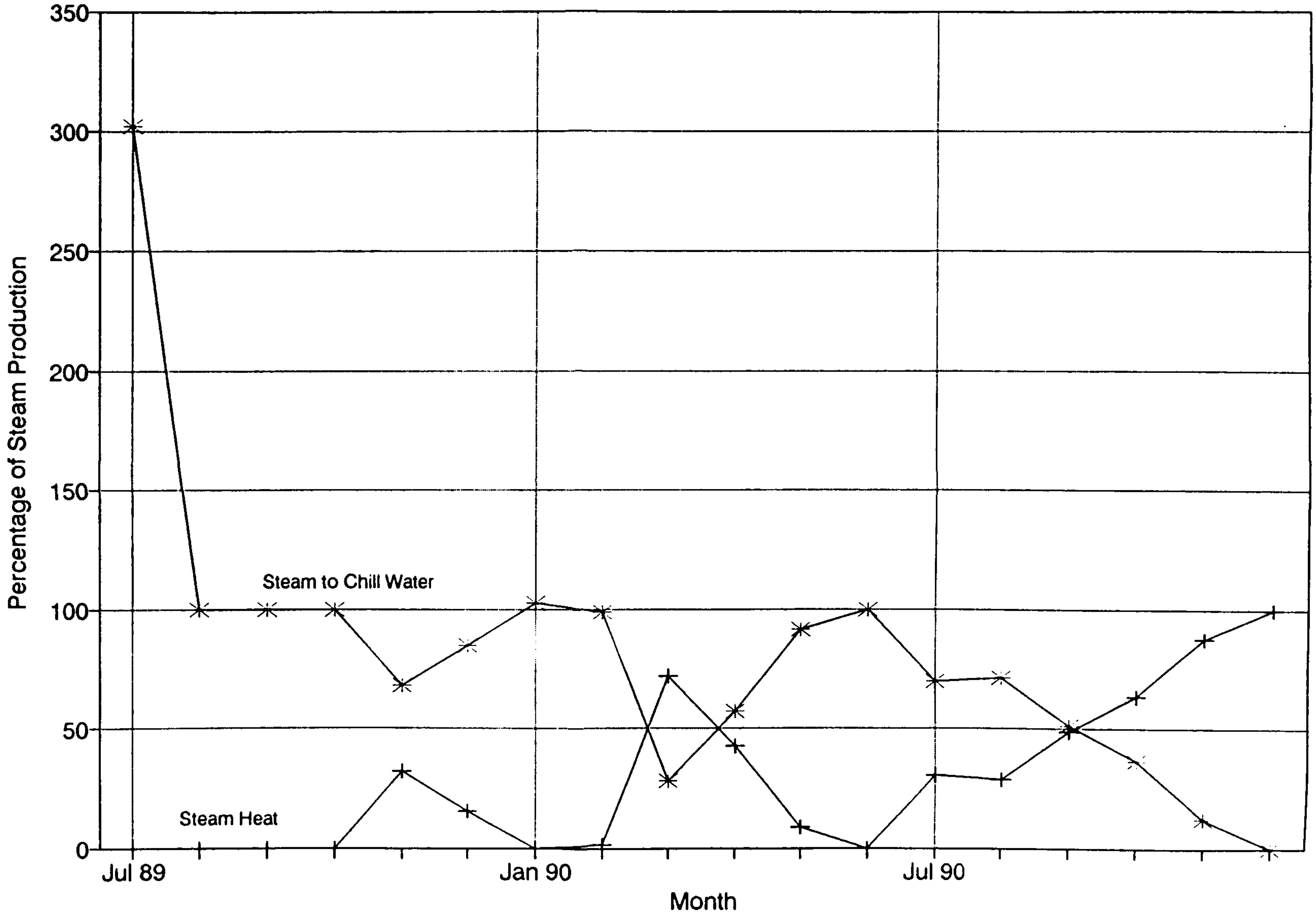

Figure D-6. Steam Use as a Proportion of Production.

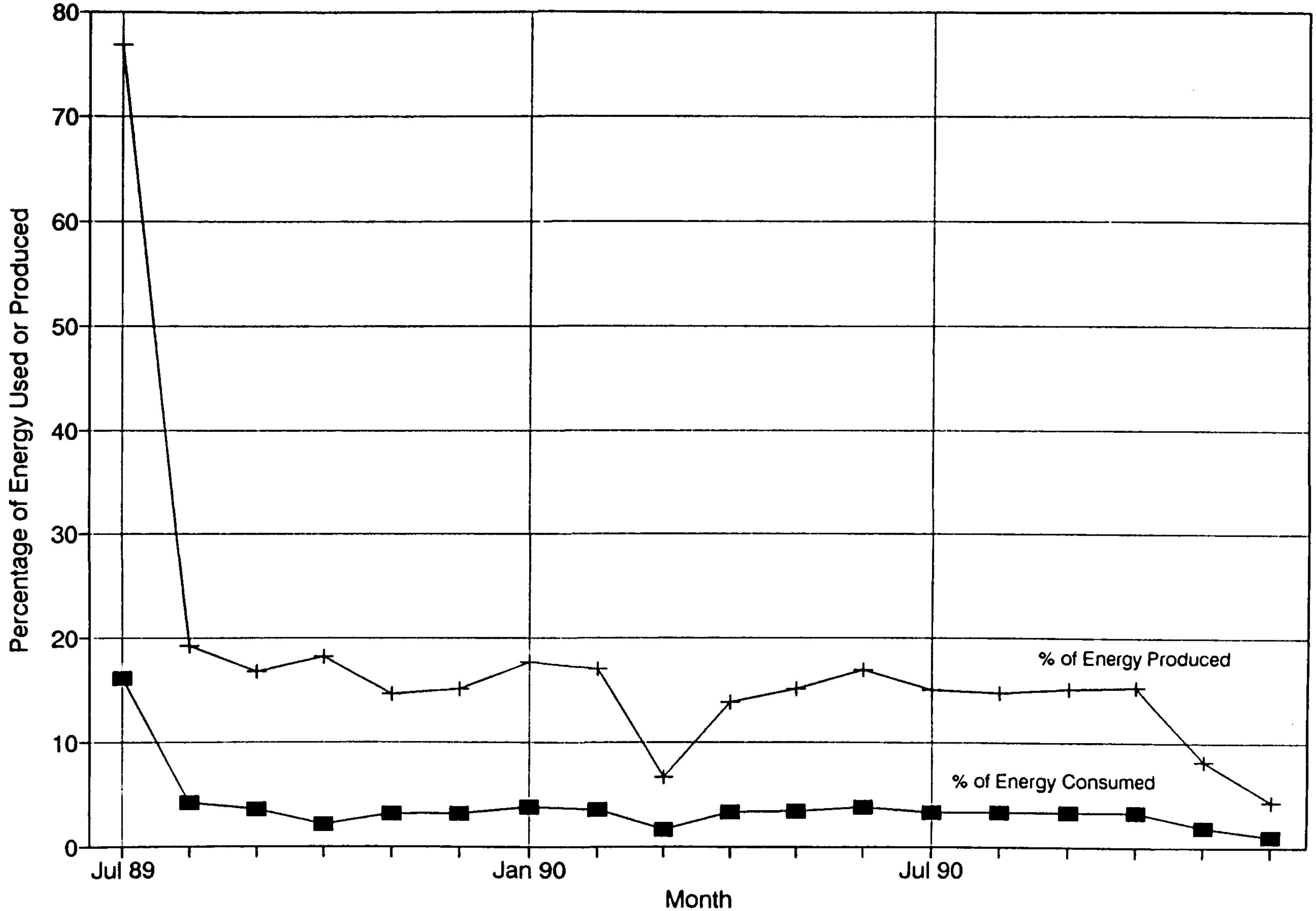

Figure D-7. Plant Parasitic Electricity Use.